AFIT/GCA/LAS/93S-6

QUANTIFICATION OF UNCERTAINTY IN THE REMEDIAL INVESTIGATION/FEASIBILITY STUDIES PROCESS

THESIS

Kurt C. Held, Captain USAF

Perry J. Shepler, Captain, USAF

AFIT/GCA/LAS/93S-6

AFIT/GCA/LAS/93S-6

QUANTIFICATION OF UNCERTAINTY IN THE REMEDIAL INVESTIGATION/FEASIBILITY STUDIES PROCESS

THESIS

Presented to the Faculty of the School

of Logistics and Acquisition Management

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Cost Analysis

Kurt C. Held
Captain, USAF

Perry J. Shepler
Captain, USAF

September 1993

Acknowledgments

In completing this research we extend our appreciation to our thesis advisors, Dr. Roland Kankey and Capt Robert Wilson for their guidance and assistance when we faced numerous roadblocks in accomplishing our research.

A special thanks goes to Bob Moore, Chief, Environmental Restoration Division, HQ Air Combat Command at Langley AFB. Without his support this thesis would not have been possible. Through his efforts, we were provided access to the necessary information found at the Army Corps of Engineers, Omaha District.

We need to also thank the Corps for allowing us to come to their offices and to obtain the necessary information for our thesis. The support they gave us was outstanding.

Finally, we give our most sincere appreciation and thanks to our wives, Diane and Chris, for their unwavering support when we were struggling through our research efforts.

Kurt Held

Perry Shepler

Table of Contents

Page

Acknowledgements ii

List of Figures vi

List of Tables vii

Abstract viii

I. Introduction 1
   General Issues 1
   Research Objective 6

II. Background Literature 8
   Environmental Restoration Laws 8
      Comprehensive Environmental Response, Compensation, Liability Act (CERCLA) 9
      Superfund Amendments and Reauthorization Act (SARA) 9
      Defense Environmental Restoration Program (DERP) 10
      Defense Environmental Restoration Account (DERA) 10
   IRP Sites, Zones, and Operable Units 11
      Sites 11
      Zones 12
      Operable Units (OUs) 13
   Environmental Cost Engineering (ENVEST) Model . . . 15
      Project Definition 17
      Phase Definition 17
      Technology/Treatment Train Identification . . . 18
      Model Processing 18
      Cost Modifiers 21
      Reports 21
   Uncertainty Analysis 22
      Estimator/Expert Judgement 25
      Sensitivity Analysis 25
      Prediction Intervals 26
      Monte Carlo Simulation 26

Page

Restoration Cost Estimating Uncertainties. 27
Models and Methodologies Used to Quantify Uncertainty in Environmental Restoration Estimates. 29
HAZRISK®. 30
Modular Oriented Uncertainty System (MOUSE) and AutoMOUSE 30
The Independent Cost Estimating Contingency Analyzer (ICECAN) 31
Probabilistic Cost Analysis 31
Influence Diagrams. 32
Modification of DOE Method for Contingency. . 33

III. Methodology. 34
Data Collection 34
Cost Interval Development 35

IV. Data Collection and Analysis 36
IRP Cost Data Search. 36
Wang Based Information Management System - Environmental Subsystem (WIMS-ES) 40
Database Development. 42
Air Combat Command (ACC). 43
US Army Corps of Engineers - Omaha District (COE) 45
Data Standardization. 48
Model Development 49
Regression Methodology. 49
Regression Cost Model Hypotheses (Step 1) . . 51
Identification of the Cost Driver Variables (Step 2). 55
Definitions of Variables Selected 57
Data Normalization (Step 3) 57
Specification of the Model (Step 4) 59
Cost Model Regression Methodology (Step 5). . 60
Diagnostics of the Regression Results (Step 6). 61
Model Selection 72
Cost Interval Development 75
Application of Cost Interval Tables 79

Page

V. Conclusions and Recommendations 83
Research Findings. 83
Further Research 85
Conclusion 87

Appendix A: RI/FS Database 88

Appendix B: RI/FS Cost Intervals 90

Appendix C: RI Cost Intervals. 100

Appendix D: Model SAS Computer Programs. 106
Model 1 Program. 106
Model 2 Program. 107
Model 3 Program. 108
Model 4 Program. 109

Appendix E: Model 3 SAS Output 110

Bibliography. 119

Vita. 125

List of Figures

Figure		Page
1	The IRP Process	2
2	Air Force Sites, Zones, and OUs	13

List of Tables

Table		Page
1.	Level of Productivity	21
2.	Model 1 - Statistics	61
3.	Model 2 - Statistics	63
4.	Model 3 - Statistics	66
5.	Model 4 - Statistics	69

Abstract

This thesis developed a method to bound cost estimates with a prediction interval of costs for the Remedial Investigation/Feasibility Study (RI/FS) phase of the Installation Remediation Program (IRP) process. The prediction interval provides a reasonableness cross check for RI/FS project cost estimates.

To develop the cost bounds, three major activities occurred. First, a database was developed from RI/FS projects managed by the Army Corps of Engineers. Second, a regression cost model was developed from the observations in the database. Third, a prediction interval specified at the 70 percent confidence level was derived from the cost model. This prediction interval provides a method to cross check RI/FS cost estimates. The prediction interval also provides a heuristic to bound RI/FS point estimates to incorporate uncertainty.

There are limitations to the cost model which affect the use of the cost intervals. The observations used to develop the cost model were limited to RI/FS projects whose field activities only included soil boring and monitoring well activities. The cost intervals should only be applied to similar type projects.

QUANTIFICATION OF UNCERTAINTY IN THE
REMEDIAL INVESTIGATION/FEASIBILITY STUDIES PROCESS

I. Introduction

General Issues

During the 1970s the United States government became increasingly aware of the fact that many of the past practices for storing and disposing of hazardous waste materials were beginning to pose a threat to both human health and the environment. Storage and disposal sites were releasing hazardous substances and pollutants into the environment. The incident in Love Canal, New York, caused state authorities to evacuate the entire community because of suspected health problems caused by a leaking hazardous materials waste site. Incidents of this type caused a public outcry for the government to take action (2:104 and 42:3).

In response to this public outcry, the United States Congress in 1980 passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) to stop the release of hazardous materials from hazardous waste sites (42:3,11:3-9). The intent of CERCLA was to provide a national response to releases of hazardous materials which pose a threat to human health or the environment (5:5). Commercial/industrial practices and sites were the primary

targets of CERCLA. The Department of Defense (DOD) and the Air Force were initially exempted from CERCLA. However, because of the Superfund Amendments and Reauthorization Act (SARA), the Air Force eventually had to comply with the requirements of CERCLA. The Installation Restoration Program (IRP) became the process by which the Air Force met these requirements (11:3-7 to 3-9).

The purpose of the IRP is to identify and cleanup past waste sites that have the potential of adversely affecting human health, public welfare or the environment (5:1). The IRP process consists of five primary phases: Preliminary Assessment/Site Investigation (PA/SI), Remedial Investigation/ Feasibility Study (RI/FS), Record of Decision (ROD), Remedial Design/Remedial Action (RD/RA), and Close-out. Figure 1 illustrates the flow of these five phases.

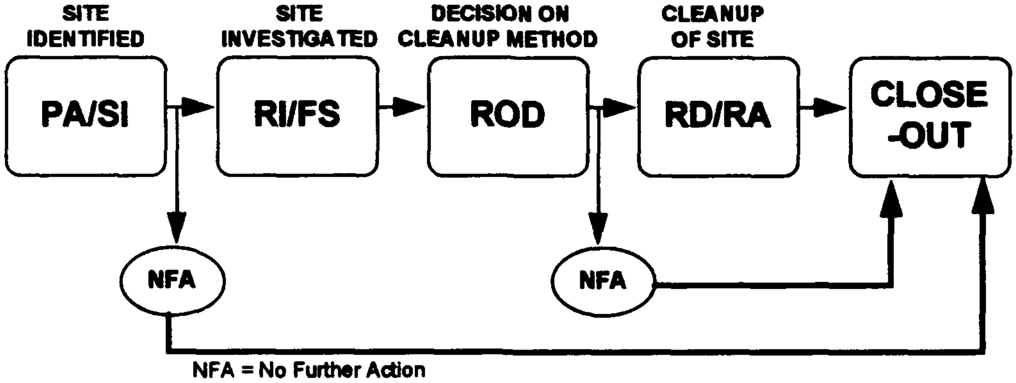


Figure 1. The IRP Process

Phase one, the Preliminary Assessment/Site Investigation (PA/SI), determines whether contamination at a

site occurred in the past and if the contamination poses a threat to human health or the environment (11:1-4). The PA consists of reviewing records, examining and comparing aerial photographs, interviewing workers (past and present), and investigating other sources of information to help determine if a threat exists (11:5-21). The SI gathers additional information not found in the PA, but required to determine whether to proceed to the next phase of the IRP, or to take no further action (11:1-4)[1]. The purpose of the PA/SI is not to fully investigate the site, but to determine if the Air Force should perform a Remedial Investigation/ Feasibility Study.

Phase two, the Remedial Investigation/Feasibility Study (RI/FS), fully investigates a site to determine the extent of contamination and evaluate the potential of alternative methods for cleaning the site (11:1-5). The RI/FS concludes with either a recommendation of no further action (when the site is no longer considered a threat to human health or the environment) or with a recommended methodology/technology for removing the contamination.

Phase three, the Record of Decision (ROD), is a formal agreement between the environmental regulators and the Air Force on the cleanup process (5:43). The ROD identifies actions the Air Force must take to remediate a site. Actual

[1]The No Further Action alternative is taken once a site is determined not be a threat to human health or the environment.

cleanup activities may not begin until the regulatory agencies agree with the Air Force's course of action and sign the ROD (11:1-2).

Phase four, the Remedial Design/Remedial Assessment (RD/RA) consists of designing and implementing the cleanup alternatives recommended in the FS and agreed to in the ROD. During the RD, the Air Force develops specifications and designs for the cleanup alternative (11:5-81 to 5-82). During the RA, the Air Force constructs and operates the cleanup alternative designed during the RD. The RD/RA also frequently includes post cleanup activities, such as soil and water sampling, to verify the Air Force restored the site to an acceptable condition (11:1-6).

Phase five, close-out, occurs when the site is no longer a threat to human health or the environment. Also, close-out can occur when Applicable or Relevant and Appropriate Requirements (ARARs) promulgated by the ROD are satisfied (11:5-95).

Funding for the IRP comes from the Defense Environmental Restoration Account (DERA). DERA is a special account dedicated to DOD environmental cleanup activities (5:1). Organizations request DERA funds annually, but can only use the funds for one year.

A problem faced by most IRP project managers (PMs) is how much DERA funding to request each year. The DERA

funding process requires the PM to provide a point estimate, i.e. a single number. Providing a single number is difficult because of uncertainty involved in IRP projects. Examples of uncertainties encountered by PMs include the amount of information available regarding types of contaminants, quantity and concentration of contaminants, and realism of the cleanup schedule.

To help PMs prepare more accurate estimates, the Air Force Civil Engineering and Support Agency (AFCESA) contracted with Delta Research Corporation to develop the Environmental Cost Engineering (ENVEST™) model (9:1-3)[2]. ENVEST™ estimates the cost of all phases in the IRP process using parametric estimating techniques. The Department of Defense has congressional authority to use ENVEST™ for developing budget estimates for environmental cleanup projects (17).

The developers of ENVEST™ also faced the uncertainty problem. Currently ENVEST™ does not incorporate factors to quantify specific areas of uncertainty in an estimate. It does add a percentage to total cost, defaulted at 25 percent, as a method to attempt to provide contingency funds for uncertainty (9:6-5). The model does not provide adequate justification for the default percentage (43). Dr. Rita Gregory, Director, Construction Cost Management,

[2]Version 1.0 was released in 1992. The latest version as of publication of this thesis is version 2.0.

Headquarters AFCESA, suggested as a research topic, the development of a method for quantifying cost uncertainty into estimates generated by the ENVEST™ model.

Review of environmental cleanup data, discussed in the IRP Cost Data Search section, indicated that sufficient information was not available to directly quantify areas of uncertainty. Sufficient data did exist to develop cost intervals. While these intervals would not identify and quantify specific areas of uncertainty, the intervals could provide a method for capturing and incorporating a measure of uncertainty into a point estimate. Due to the effort required in developing these intervals, this research is limited to RI/FS project cost estimates.

Research Objective

Our research will attempt to develop a method to bound the point estimates with a range of costs for the RI/FS phase of the IRP process. To estimate this range we will calculate cost intervals which are defined by the high and low bounds. These bounds depend upon the dispersion we encounter in RI/FS field data, desired probability of the actual costs falling within the interval, and a measure of the difference between the estimated site and the average site in our data.

To achieve the objective of this thesis, we must first gather sufficient data to develop a parametric cost model to

estimate the individual RI/FS project costs. Our research must then derive a prediction interval around the predicted costs. Finally, we must develop cost intervals which when applied to an RI/FS estimate provide a range of costs at a specified confidence level. The conclusion of this thesis will be a recommendation to AFCESA on cost intervals, which can be used to cross-check the ENVEST™ estimates for RI/FS projects. Also, areas of additional research will be suggested.

II. Background Literature

This chapter is designed to provide the reader with a historical perspective of the Installation Restoration Program (IRP) and different methods for incorporating uncertainty into restoration[3] (cleanup) cost estimates. First, this chapter provides a review of the environmental laws which shaped the IRP process. Second, it explains how ENVEST estimates restoration costs. Third, some general information on different methodologies for quantifying and incorporating uncertainty into cost estimates will be provided. Finally, models and techniques currently used or proposed for incorporating uncertainty into the restoration process will be reviewed.

Environmental Restoration Laws

The IRP functions chiefly under the purview of two environmental laws: the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Superfund Amendments and Reauthorization Act (SARA). The IRP has existed since 1978. CERCLA and SARA codified the

[3]For technical accuracy, throughout the remainder of this thesis the term restoration will be used to refer to the entire process of cleaning up a site. Restoration is divided up into two parts. The investigation, the PA/SI and RI, which is the process of determining what is at a site. The remediation, the FS, RD/RA and closeout, which is the process of actually removing the contaminates from the site. These terms will be used to refer to that part of the restoration process; however, the separation between investigation and remediation is not always well defined. Occasionally other authors will include both the RI and FS in the investigation or the remediation.

entire restoration process into law and established a framework for all restoration projects, including DOD's IRP (5:5). These two laws require cleanup procedures to comply with all other existing environmental laws and regulations, such as the Clean Air Act and the Wilderness Act (5:5). What follows is a description of these laws and their effect on the IRP.

Comprehensive Environmental Response, Compensation, Liability Act (CERCLA). CERCLA, known as Superfund, was enacted in 1980 and was expected to last for five years (40:2811). The intent of CERCLA was to provide a national response for cleaning up hazardous waste disposal sites and to establish a National Priorities List (NPL)(11:3-7). The NPL contains sites specified by CERCLA that require priority for restoration due to the severity of the contamination. CERCLA established a framework on how private industry will respond to releases of hazardous substances, pollutants, or contaminants (6:11). CERCLA also defined the roles of the EPA and appropriate state agencies, and provided guidance on how these agencies would interact with each other (6:13).

Superfund Amendments and Reauthorization Act (SARA). Since CERCLA was only intended to last 5 years, Congress enacted SARA in 1986 to reauthorize CERCLA. Several new provisions to CERCLA were added by SARA. Section 211 is the most important new provision to the Air Force. The

provision established the Defense Environmental Restoration Program (DERP) and the Defense Environmental Restoration Account (DERA)(5:1). The current IRP is part of DERP and funding for IRP comes from DERA.

<u>Defense Environmental Restoration Program (DERP)</u>. The DERP required the DOD's IRP, which existed prior to CERCLA, to conform with the EPA's guidelines, rules, regulations, and criteria for hazardous waste site restoration established under CERCLA (5:1). Two objectives of DERP are:

> (1) Identification, investigation, research and development, and cleanup of contamination from hazardous substances, pollutants, and contaminants.
>
> (2) Correction of other environmental damage (such as detection and disposal of unexplored ordnance) which creates an imminent and substantial endangerment to the public health or welfare of the environment. (6:14)

These objectives make up the current IRP in its present form.

<u>Defense Environmental Restoration Account (DERA)</u>. According to the DERA eligibility and programming guidance dated 1 March 1993:

> The DERP is funded by a special transfer account, the Defense Environmental Restoration Account (DERA) established by 10 USC 2703. The deputy Assistant Secretary of Defense (Environment) DASD/E centrally manages the account, including developing and defending the budget, and allocating funds between the Army, Navy, Air Force, and Defense Logistics Agency (hereafter

referred to as the "DoD Components") based on identified requirements and their priority. Funds are transferred from the Environmental Restoration, Defense appropriation account to DoD Component appropriations accounts (e.g. Operations and Maintenance - 3400 O&M, Procurement - 3080 Equipment, Research and Development - 3600 RD&TE). (7:1)

IRP Sites, Zones, and Operable Units

Thus far the IRP process has been discussed as it applies to contaminated sites. However, when a project manager is developing a strategy for cleaning up sites at an Air Force installation, he/she will try to optimize the restoration process by combining activities around sites with similar problems (e.g. fire training pits) or sites that contribute to a single problem (e.g. base ground water contamination). These grouped sites are defined as zones and operable units (OUs).

An understanding of zones and OUs is important from a cost estimating viewpoint. ENVEST™, as of version 1.5, estimates RI/FS costs at the site level (10:7-4 to 7-13). However, our data search revealed that estimates are often done by OUs. In fact, many RI/FS efforts were contracted as multiple OUs.

Sites. An IRP site "is the basic unit for planning and implementing 'response actions'" (11:3-5). It is any place where hazardous material was "stored, disposed of, placed, or has otherwise come to be located" and the material has

since been released (11:3-5). A site can range from a designated hazardous waste storage area to a small spill site.

Zones. Zones are geographically connected areas, which are managed as single investigative units (11:97). They are tools used for managing, organizing, and defining areas of investigation (11:97). If an installation is preparing to investigate possible sources of ground water contamination by conducting a PA/SI, the project manager would define the zones to optimize the investigation. In the example shown in Figure 2, the project manager could use the ground water divide, a hydrological separation of the ground water table, to define two zones on the installation. By defining two zones the project manager can better focus the data gathering process during the PA/SI into related groups.

Defining a zone is not limited to any particular geological characteristic. A zone may be a grid block of land, a natural land division (a stream), a geologically distinct area (sand versus clay soil), or hydrologically distinct area (ground water divide) (11:97). The objective is to define the zone in a logical manner, which improves investigation of the zone during the PA/SI and RI (11:100). Zones "are technically-oriented management tools for organizing and defining areas of investigation" (6:97).

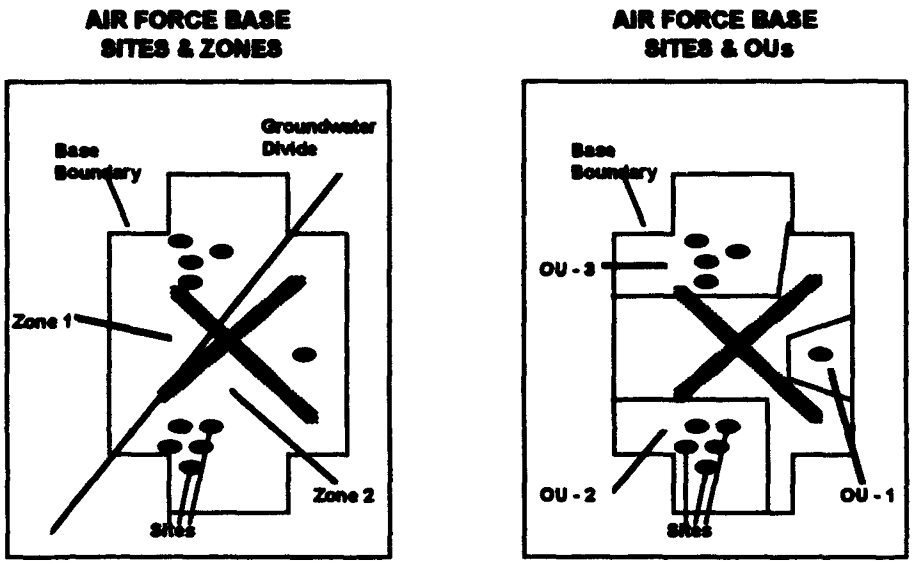


Figure 2 Air Force Sites, Zones, and OUs (6:103)

Operable Units (OUs). OUs, like zones, are also intended to optimize environmental restoration strategies. The focus of OUs is to facilitate agreements between the Air Force and environmental agencies (6:100-102). Any cleanup action that can be implemented by itself (e.g. ground water cleanup) can be designated as an OU (11:3-4). An OU can take many shapes and sizes (see Figure 2). They can be made up of one or several sites, or conversely, one site may be divided into many OUs. The object as stated in the Air Force Environmental Restoration Program Management Action Plan Guidebook is to:

> ...establish a logical sequence of decisions that addresses contamination releases at an installation in a comprehensive fashion. (6:100)

OUs speed up the remediation process and lower the cost by combining cleanup actions in a logical manner which facilitate agreements between the Air Force and environmental agencies (10). For example, an OU consisting of several sites with the same problem can complete the ROD process faster and for less money than each site individually. This is because many of the repetitive administrative and legal requirements can be combined.

OUs are typically defined in a variety of ways. The sites included in an OU often change. For example, the Air Force and an environmental agency may agree on a proposed action for three out of four sites in an OU. Rather than delay the cleanup of the OU over the disagreement on one site, the Air Force can remove the site from the OU. This allows the Air Force and environmental agencies to come to an agreement and proceed with cleanup process for the remaining sites in the OU. Examples of how OUs are defined include:

- Areas with similarly contaminated waste materials
- Areas with similar geographical locations
- Areas that may be remediated using a similar technique or within a similar time frame.
- Areas that are amenable to being managed in a single RI/FS (6:101)

Environmental Cost Engineering (ENVEST) Model

Prior to the creation of ENVEST™, program managers relied on estimating techniques and models developed for construction engineering projects to estimate cleanup costs. Several estimating models, such as the Micro-Computer Aided Cost Estimating System (M-CASES) and the Air Force Construction Cost Management System (CCMAS) attempted to fill the gaps (9:1-4; 11:4-11). However, it was apparent that a comprehensive cost estimating model specifically designed for environmental restoration was required. Mr. Gary Vest, the Deputy Assistant Secretary of the Air Force (Environment, Safety and Occupational Health) stated:

> After surveying available cost estimating tools, we determined there was not a comprehensive tool available which would effectively estimate all phases [of the IRP process]. (8)

To fill this gap, the United States Air Force Civil Engineering Support Agency (AFCESA) contracted for the development of the Remedial Action Cost Engineering and Requirements (RACER) system. The RACER system, projected to be released in fiscal year 1994, is planned to be a comprehensive remediation expert system (17). The intent of RACER is to provide project managers with a tool to help develop and evaluate alternative remediation approaches and estimate the cost of each alternative (9:1-3).

RACER is planned to consist of three components. The first component is the Remedial Action Assessment System

(RAAS)[4]. This is an expert system which identifies applicable technologies for remediating contaminants at a site (9:1-3). Multi-purpose Environmental Pollution Assessment System (MEPAS) is the second component (43). MEPAS will be used to develop risk and health assessments (43). ENVEST™, the third component, has been fielded and is a cost estimation and analysis tool that can be used to compare the cost of alternative cleanup approaches identified with RAAS (9:1-3). ENVEST™ is capable of estimating the cost of the RI/FS and RD/RA phases of an IRP project (9:1-3). As of version 1.5, ENVEST™ is limited to cost models for technologies associated with three types of sites: fire training areas, landfills, and fuel storage areas (including underground storage tanks). These three types of sites comprise approximately 50 percent of all IRP sites (9:1-3).

The ENVEST™ estimating process includes six basic steps:

- Project Definition
- Phase Identification
- Technology/Treatment Train Identification
- Model processing

[4] RAAS is proprietary, developed by Battelle Corp for the Department of Energy. It will be provided free to the Air Force. As publication of this thesis, the use of RAAS was being reconsidered. A final decision to use RAAS in RACER will be made after beta testing by the DOE in FY94 (17).

- Cost Modifiers
- Report Generation (9:1-4)

The description of each step, taken from the ENVEST™ users manual, is provided below (9:1-5 to 1-7)[5].

Project Definition. Project Definition consists of providing general information about the project at the project level and at the site level[6]. Project level information includes: project identification, location, project name, comments, preparer's name, and date of estimate. Site level information includes: site identification, site name, comments, preparer's name, and date of estimate. The location determines the location cost modifiers which adjust the labor, material, and equipment costs for area cost factors. Unit prices for Atlanta, Georgia serve as the reference datum for prices in other locations (9:1-5).

Phase Definition. The ENVEST™ system consists of separate models for RI/FS, RD, and RA phases of remediation. The RA models include activities/costs for O&M and other project activities. Costs can be estimated for one or more phases of a project within a single estimate (9:1-5).

---

[5]This section was taken directly from the ENVEST™ Model Report handbook with modifications to the text.

[6]A project is defined by ENVEST™ as an entity made up of multiple sites. OUs and zones are not used by ENVEST™. ENVEST™ estimates cost at the site level and then sums the site costs into a project cost.

Technology/Treatment Train Identification. The RA cost model is a collection of independent cost models, with each model being specific to a particular remediation technology. To generate a RA cost estimate, the technology or set of technologies (referred to as a treatment train) must be identified. This can be accomplished by using RAAS or RI/FS field notes to determine the applicable treatment train alternatives for the site in question (9:1-5).

Model Processing. Cost estimates are generated by processing each of the models that has been identified for a project. All the models within ENVEST™ are based on a parametric modeling methodology, and use four basic steps. The steps are identification of required parameters, modification of secondary parameters, calculation of assembly quantities, and estimation of assembly costs (9:1-5).

Identification of Required Parameters - The minimum amount of information that is required to create a cost estimate. There are no defaults; values are site-specific. A reasonable cost estimate can be generated from the required parameters. An example of required parameters for Air Stripping (a method for removing pollutants for the air include:

- Influent Flow Rate
- Overall System Efficiency

- Startup Period
- O&M (Operations and Maintenance) Period
- Safety Level
- Location (9:1-5)

Modification of Secondary Parameters - Unlike required parameters, secondary parameters have defaults that are determined by the model. Default values are computed by algorithms based on the engineering design and model assumptions. A reasonable cost estimate can be created using only the required parameters. When more detailed information is known secondary parameters can be modified to create a more precise site-specific estimate. An example of secondary parameters for Air Stripping include:

- Number of Stripper Towers
- Diameter of the Towers
- Height of Packing Material in the Tower
- Length of Influent and Effluent Piping
- Type of Material used for Piping (9:1-5 to 1-6)

Calculation of Assembly Quantities - Computed using the parameter values and the engineering design and model algorithms that form the basis of the model. To continue with the air stripping example, assume that the influent flow rate is 30 gallons per minute and medium overall system efficiency (required parameters). The model selects one 2.0 foot diameter tower with a 19.0 foot packing height as the secondary parameter default along with 100 linear feet of

PVC (a type of plastic) piping for the effluent. The assembly quantity algorithms use engineering tables and equations. These determine the diameter of pipe based on the influent flow rate. In this example, the model selects 200 linear feet of 2 inch diameter PVC piping. The quantities calculated by the model are based on a generic design and can be adjusted as necessary to reflect an actual design (9:1-6).

Estimation of Assembly Costs - Computed using assembly quantities and adjusted assembly costs. Basic assembly costs include the costs of labor, equipment, and materials, and the sum of the assembly line costs from the Corps of Engineers' Unit Price Book assuming normal construction in Atlanta, Georgia. These costs are adjusted to account for the reduced level of productivity associated with safety level requirements. Safety levels (A,B,C, and D) are based on the Occupational Safety and Health Administration (OSHA) regulations in 29 CFR Part 1910[7]. Safety level E corresponds to the EPA "No Hazard" designation. The productivity factors, as shown in Table 2, are based on information in (EPA/600/2087/087) "Compendium of Costs of

[7]Safety level determines the type of personal protection (safety equipment) workers wear to protect themselves from hazardous materials. The levels range from E, no protection, to level A, a fully encapsulating suit with self-contained air (9:1-7 thru 1-8). The safety equipment can be very restrictive which reduces worker and conseqeently equipment productivity.

Remedial Technologies of Hazardous Waste Facilities" (9:1-6).

Table 1

Level of Productivity (9:1-7)

SAFETY LEVEL	**LEVEL OF PRODUCTIVITY** **LABOR**	**EQUIPMENT**
A	15%	50%
B	25%	60%
C	50%	75%
D	75%	100%
E	100%	100%

Cost Modifiers. ENVEST™ cost modifiers calculate indirect costs to complete the cost estimate generated by the models. These costs include:

- Contractor Indirect Overhead and Profit
- Escalation
- Contingencies
- Project Management (9:1-7)

Reports. Reports are organized by the Code of Accounts and include both direct and indirect costs. These reports can be generated after calculating costs for the remedial process(es) identified by the user (9:1-7).

Uncertainty Analysis

Cost estimating by its very nature involves uncertainty. The Air Force System Command (AFSC) Cost Estimating Handbook[8] makes this point clear when it states, "risk and uncertainty refer to the fact that, because a cost estimate is a prediction of the future, there is a chance that estimated cost may differ from actual cost" (4:13-1). If actual costs are substantially higher than estimated costs, then the available funding may not be sufficient to cover costs. Since cost estimating involves uncertainty, the issue is to identify the impact of uncertainty on the estimate.

To begin understanding uncertainty, it should be noted that uncertainty and risk are not synonymous[9]. Risk is defined as, "a situation in which the outcome is subject to an uncontrollable random event stemming from a known probability distribution" (4:13-4). In other words, there is a known probability that an event will occur which can impact the outcome of a situation. In the case of an IRP project, an estimator might know that there is a 80 percent probability of rain in January and that rainy weather impacts work schedules.

---

[8] Air Force Systems Command was merged with Air Force Logistics Command in 1992 to form Air Force Materiel Command.

[9] Risk in the context of this thesis refers to cost risk, and should not be connected with the concept of a health or safety risk.

Uncertainty on the other hand is defined as, "a situation in which the outcome is subject to an uncontrollable random event stemming from an unknown probability distribution" (4:13-4). In this case, an unknown event can occur and the probability of the event occurring is unknown. For example, an unknown event, such as a regulatory rule change, can occur, but the chances of this event occurring are unknown.

The distinction between risk and uncertainty is emphasized because the cost of risk on a project can be easily calculated and included in an estimate. Using the rain example again, if an estimator knows that there is an 80 percent probability of rain on any given day in January, and he/she also knows that a rain delay will cost an additional $100 per day, then he/she can include that cost in the estimate. In this case the calculation would be:

Probability of rain *times* the cost of a rain delay per day *equals* the additional cost per day

0.80 x $100/day = $80/day

The estimator would include an additional eighty dollars per day for each day of work in January[10]. Uncertainty cannot

[10]This example is very simplistic and ignores important variables such as the confidence level. The purpose is to demonstrate that if the probability distributions were known, then the task of estimating the unknown events is much simpler.

be calculated in this manner. The probability is unknown, so a different methodology must be considered.

Classical cost estimating methods divide cost uncertainty into two categories: cost estimating uncertainty and requirements uncertainty (4:13-6 to 13-8). Cost estimating uncertainties are errors in the estimate when the requirements stay constant (1:10-26). In this case, the uncertainties in the estimate are associated with the estimating technique. Requirements uncertainties are changes to the program being estimated, for example additional hazardous waste drums must be analyzed (1:10-26). A Rand Corporation report states that the majority of errors, in acquisition estimates, are caused by requirements uncertainties (3:131).

Requirements uncertainty may also be a strong driver of cost deviations in environmental restoration projects. Quantification of uncertainty into a cleanup estimate is based on available data and assumptions made. For example, if a project manager is uncertain about the contaminants in a site because of limited data, the estimate may reflect this uncertainty as an increase in the estimated cost.

There are numerous techniques for identifying, measuring, and incorporating uncertainty in an estimate. These techniques range from simple subjective judgment calls to sophisticated statistical methodologies. The following paragraphs provide a synopsis of four techniques recommended

in the Air Force Base Level Cost Analysis Handbook and the AFSC Cost Estimators Handbook. These techniques are used extensively in acquisition estimates.

Estimator/Expert Judgment. This is one of the oldest methods employed to account for uncertainty in an estimate (1:10-26). With this technique, the estimator[11] reviews all the assumptions used in making the estimate, the information available at the time of the estimate, and any other information available at the time of the estimate (1:10-26). After evaluating this information, the estimator adjusts the estimate by some percentage. For example, the estimator may believe that his/her estimate captures 75 percent of the costs, so he/she adjusts (increases) the estimate by one-third. Although this technique has been used successfully, the estimator and experts, if used, must be highly experienced in the product they are estimating for the estimate to have any validity (1:10-26).

Sensitivity Analysis. Sensitivity analysis involves changing key assumptions or parameters of the estimate while holding all the other parameters constant (1:10-27). By changing the parameters the estimator can determine the impact of areas of uncertainty on the estimate. For example, changing the number of water samples analyzed during a RI/FS may change the RI/FS costs significantly.

---

[11] An expert in the system or area being estimated may also make judgments about the estimate.

Changing the type of analysis may have very little impact on the costs. In this example the estimate is very sensitive to the number of water samples analyzed. An estimator would be more concerned with uncertainty in the number of water samples analyzed because of its effect on cost.

Prediction Intervals. Prediction intervals can be used as a measure of uncertainty for estimates based on a cost estimating relationship (CER)[12]. The uncertainty is expressed using the standard error of the estimate (SEE)[13] around the regression line developed in the CER (1:10-27). The value of having prediction intervals is that the analyst can make objective, definitive probability statements for a given range around the point estimate (1:10-27).

Monte Carlo Simulation. Monte Carlo Simulation is a statistical simulation technique which determines uncertainty by developing a probability distribution of the estimated cost. This technique assumes that the cost probability distribution of a project can be found by aggregating the cost distributions of all the cost elements which make up the total project costs.

The basic steps to Monte Carlo simulation are the following: First, the estimator breaks out the cost elements

---

[12]A CER is a mathematical relationship between a dependent variable, Y_i, and one or more independent variables, X_i. For example, $Y_i = b_0 + b_1 X_i$. Regression analysis is often used to develop a CER.

[13] SEE measures the typical amount that the actual values of dependent variable, Y_i, in a CER, varies from the estimated value of that variable. A complete discussion of CERs and regression analysis can be found in most statistics books.

of a project. For a given RI/FS these might include well borings, sampling and analysis, and report writing. Second, a probability density function (pdf) and cumulative density function (CDF) are developed for each cost element[14]. Third, a random number is chosen between zero and one and is located along the Y axis of the CDF. A horizontal line is projected along to the CDF curve and the corresponding cost (X axis) value is measured for each cost element. Finally, costs for each element are summed to arrive at the total cost of the project at that probability. The process is repeated numerous times until a probability distribution for the total cost is developed. With a total cost distribution, an estimator can then estimate the cost of the project at a given confidence level.[15]

Restoration Cost Estimating Uncertainties

Environmental cost estimating has several unique problems which can complicate the estimator's job. This may make using uncertainty techniques difficult. Some of these problems, such as incompletely defined requirements, changing rules and assumptions, and multiple regulatory agencies are discussed below.

---

[14]A pdf and CDF are graphical representations of a continuous random variable's probability. Development of pdf and CDF is not easily done, and this step in Monte Carlo simulation can be very time consuming. The required inputs are the high, low, and most likely expected costs and the distribuition shape for the cost elements. Computer software packages, such as MathCad and Minitab can be used to estimate the distributions.

[15]Monte Carlo simulation generally assumes independence between the cost elements.

First, the requirements are not clearly defined early in the restoration process. Estimates are required very early in the program when very little information is available about the concentration and extent of contamination, types of contamination, and appropriate technology (12:2-1).

Second, ground rules and assumptions frequently change during the restoration process (25:22). For example, Mr. Ron Lester, Restoration Program Manager, Wright-Patterson AFB, stated that the Operable Units (OUs) at Wright-Patterson AFB were regrouped (sites moved between OUs) several times. This was done to arrive at agreements as new remediation sites were discovered and additional information became available (24). Not only did the additional sites change the restoration costs, but the rearrangement of sites changed the original assumptions about each OU and thus costs.

Third, IRP projects must adhere to multiple federal and state laws and regulations (26:141). These frequently contradict each other and are interpreted differently by different government agencies. For example, the National Resource Trustee[16] for a wetland area may decide not to cleanup a site so as not to disturb the wetland area. In

[16]The National Resource Trustee acts on the behalf of the public to protect natural resources. Their responsibilities include assessing natural resource damage from implementing restoration activities (5:137).

this case, the trustee considered requirements of the Fish and Wildlife Coordination Act more important than requirements of CERCLA (5:11).

Areas of uncertainty in restoration projects are nebulous and changing. The relative youth and dynamic nature of the environmental restoration field and limited data make identification of these areas of uncertainty difficult. Areas of cost uncertainty which are prevalent throughout the literature and industry include:

- Liability Risk (Lawsuits and the cost of taking extraordinary actions to defend against a suit)
- Technology Risk (Using new technology versus proven but expensive and time consuming technologies)
- Waste Complexity (The amount and type of contaminates at a restoration site)
- Media Complexity (The nature of the soil or water which must be cleaned)
- Volume Risk (How much material must be cleaned up)
- Regulatory Risk (Changing regulations and differing interpretations by various government agencies) (37:40-46; 26:148; 12:6-2)

Models and Methodologies Used to Quantify Uncertainty in Environmental Restoration Estimates. Despite these difficulties, several models and techniques are available for quantifying restoration uncertainty. Below is a synopsis of the different models and techniques available.

HAZRISK®. The Independent Project Analysis (IPA) Corporation developed the HAZRISK® model to estimate cost, schedule, and contingency[17] for hazardous waste cleanup sites (37:65). Estimates from HAZRISK® are based on a historical database of over 150 DOE, EPA, and private industry projects (37:8). These estimates are centered around Operable Units (OU) and Solid Waste Management Units (SWUMs)[18] (37:8). The HAZRISK® model uses parametric statistical techniques to provide cost, schedule, and contingency estimates (37:6). IPA also developed numerous statistical correlations between restoration costs and various cost drivers. These correlations are used in developing estimates (37:18-29).

Modular Oriented Uncertainty System (MOUSE) and AutoMOUSE. MOUSE is a computerized uncertainty analysis system which is used with estimating models that consist of one or more algebraic equations (12:467). It utilizes Monte Carlo simulation to derive a probability distribution for a project's total cost (23:375). First, the user provides basic data on different input variables, e.g. distribution shape and the high and low values. A value for each input variable is drawn at random from its respective probability

---

[17]Both cost and schedule contingency.

[18]SWMUs are defined by the Resource Conservation and Recovery Act (RCRA) as any discernible unit which solid wastes have been placed at any time, regardless of whether the site was intended for solid waste or hazardous waste (10:3-5). RCRA deals with the management of solid and hazardous waste and applies to active practices, where CERCLA and SARA deals with past practices (11:3-15).

distribution. Total project cost is then computed by inputting the variable values into the estimating equations. This process is repeated numerous times until a probability distribution is developed for the total project cost (23:374-376). MOUSE allows an estimator to do complex simulation routines without a large degree of knowledge in computer programming (12:467). The model does not correlate the variables during the simulation. AutoMOUSE is a more user friendly version of MOUSE, which requires less computer programming knowledge (22:1).

The Independent Cost Estimating Contingency Analyzer (ICECAN). The ICECAN program is another Monte Carlo simulation model which produces a frequency distribution of total costs based on several random cost variables (16:1-1). Distribution types for the cost variables are: fixed, normal, discrete, or step-rectangular (16:1-1). The estimator inputs estimated costs and appropriate parameters for the selected probability distribution (16:3-1 to 3-5). The user's manual did not indicate whether the model correlates the cost variables. ICECAN is a stand alone program that does not work in conjunction with other programs.

Probabilistic Cost Analysis. The probabilistic cost analysis technique, developed by Putnam, Hayes & Barlett, Inc. (PHB), uses a decision tree analysis approach for identifying remediation cost uncertainty (12:352).

Probabilistic cost analysis investigates a wide range of alternative outcomes and systematically evaluates all major sources of cleanup cost uncertainty (32:9). Probabilistic cost analysis provides a cost range that reflects the uncertainty of key variables affecting total cost (32:9). The process entails characterizing the site, identifying potential cleanup scenarios, assessing the likelihood of each scenario, and calculating the expected values and cost distributions (32:10). The probability associated with each decision/action is determined and applied to the total project cost.

Influence Diagrams. Influence diagrams are an offshoot technique of the decision analysis concept. This technique is widely used in artificial intelligence and decision sciences. It is also being used for risk analysis (13:35). Influence diagrams evaluate external risks and their impact on correlated cost elements through a series of questions which must be answered by the estimator (13:35). One question might be, "what impact will delaying a cleanup permit have on the restoration schedule?" The next questions should address the impact of the schedule delay on the total cost.

Influence diagrams are used to investigate very complex situations and identify which risks have the most impact on the total project cost (13:39). The estimator must provide

estimates of the probabilities of the external events occurring and their associated impacts.

Modification of DOE Method for Contingency. Mr. Michael Morse, a senior analyst with Geocenters Inc., a DOE contractor, proposed a modification of the current DOE methodology (DOE Order 5700.2C) for quantifying risk in DOE projects (26:145). This approach quantifies restoration cost uncertainty by combining project definition scoring and risk analysis techniques. Project definition scoring involves identifying major cost risk factors [areas of uncertainty] and then weighting their relative importance to the major work breakdown structure elements. The probability of individual risk factors occurring is then determined (26:146). Weighting factors and probabilities are used to calculate an applied contingency rate. This contingency rate is used to determine contingency as a percentage of total costs to be included in the estimate (26:146).

III. Methodology

This thesis consisted of two specific stages. Stage one was data collection. We collected and normalized RI/FS cost data. Stage two consisted of data analysis. We developed a RI/FS cost model and developed cost intervals from the CER which can be used to provide an approximate range of RI/FS costs.

Data Collection

Two major activities occurred in stage one. First, RI/FS estimates and actual price data were collected. We collected original RI/FS estimates and actual costs from existing IRP and CERCLA databases. This effort began by searching for an IRP database within the Air Force. If an adequate database could not be found within the Air Force, then the search would expand to CERCLA databases maintained by other government organizations. If no database was available, then we would develop our own database by collecting data from primary sources, such as DERA funding documents.

The second major activity of data collection was normalization of the data. First, we segregated the RI/FS project costs by individual sites. Second, dissimilar data points were removed from the data set. Finally, we inflated or deflated the data points into a common base year. Once

the data was normalized, development of the cost model and cost intervals began.

Cost Interval Development

Three major activities occurred during this part. First, we used regression analysis to develop a cost model of RI/FS project costs. This cost model was based on actual RI/FS cost data from our database.

Second, we built prediction intervals around the predicted costs. Predicted costs were calculated by the cost model. The prediction interval gave an upper and lower bound around a predicted cost using 70 percent confidence. Cost interval factors, values that can be added and subtracted to the predicted cost to arrive at a range of costs for a given level of effort at a specified confidence level, were developed. For example, if the cost interval factor is specified at a 70 percent confidence level, then the probability of the true cost falling within the cost interval is 70 percent. This probability level was based on the samples or observations in the database.

Finally, we will built cost interval tables. Discussion of possible uses of these tables is deferred until chapters IV and V.

IV. Data Collection and Analysis

IRP Cost Data Search

To develop RI/FS uncertainty cost we needed data on actual estimates and final costs of various RI/FS projects. Ideally the data would be in the form of a homogeneous database with data on specific types of sites, e.g. fire training areas or land fills. Data from IRP projects was preferred; however, since the IRP is based on CERCLA, CERCLA projects would also be appropriate.

We initially began our search within the Air Force for any IRP cost databases or repositories of IRP costs data. We contacted the following personnel:

1. Captain Robert D. Wilson, Instructor, Environmental Management, School of Civil Engineering, Air Force Institute of Technology (AFIT/CEV)

2. Dr. Rita A. Gregory, Director of Construction Cost Management, Headquarters, Air Force Civil Engineering and Support Agency (AFCESA/DC)

3. Mr. Anthony Zugay, Technical Associate, GM-15, Base Closure Restoration Division, Air Force Center for Environmental Excellence (AFCEE/ESB)

4. Major Stewart A. Nelson, Defense Environmental Restoration Program Manager, Environmental Restoration Division, Directorate of Environmental Quality, HQ USAF (HQ USAF/CEVR)

5. Mr. Wayne Ratliff, Program Manager, Environmental Restoration Division, Headquarters Air Material Command (HQ AFMC/CEVR)

6. Mr. Robert Moore, Chief Environmental Restoration Division, Headquarters Air Combat Command (HQ ACC/CEVR).

We asked three primary questions:

1. Do you have any cost data on RI/FS projects estimated with the ENVEST model?

2. Do you have, or know of, a database which contains environmental cleanup costs. Specifically, a database which contained RI/FS estimates and final costs?

3. Where, in your opinion, is the best place to look for historical cost data on IRP sites. Specifically cost data on RI/FS.

Consistently their answers (paraphrased) were (24;18;25;33;28;44):

1. Because ENVEST is a new model, historical cost data on RI/FS or IRP project estimated with ENVEST does not yet exist in sufficient quantities for a thesis.

2. The only database which contain IRP cost data is the Wang Information Management System - Environmental Subsystem (WIMS-ES).

3. The best sources of environmental cleanup cost data are the major commands (MAJCOMS) and the service centers[19].

[19] Service centers are other federal organizations with whom the Air Force contracts IRP projects. They are used because of their expertise in environmental restoration (5:23-24). The service centers are the contracting agencies and technical managers for the restoration efforts. Service centers include US Army Corp of Engineers (COE); Air Force Center for Environmental Excellence (AFCEE), Naval Facilities Engineering Command (NAVFACENGCOM), Southern District; US Geological Survey; and HAZWRAP, a DOE contractor. (5:24)

With only the WIMS-ES database we decided to expand our investigation beyond the Air Force to other federal agencies. The following personnel and agencies were contacted:

1. Mr. Thomas Whalen, Construction Management Consultant, Superfund Division, Environmental Protection Agency (EPA)

2. Mr. Michael Morse, Senior Analyst, Geocenters, Inc.[20]

3. Mr. Jim Peterson, Civil Engineer, U.S. Army Corps of Engineers - Missouri River Division (CEMRD-ED-CV)

4. Mr. Thomas Hurley, Director for Design Policy, Assistant Commander for Engineering and Design, Naval Facilities Engineering Command (NAVFACENGCOM)

The same questions were asked. Answers were consistent except two additional databases were identified (26;41;21;31). It should be noted that except for Mr. Morse of Geocenters, Inc. the persons questioned (all from different federal agencies) were aware of ENVEST and RACER. This indicates that communication between different government agencies responsible for CERCLA/IRP projects is occurring.

One additional database identified, the Hazardous Toxic, and Radioactive Waste Historical Cost Analysis System

---

[20]Geocenters, Inc. provides cost engineering services to the Department of Energy's Sandia National Laboratories for environmental restoration programs.

(HTRW-HCAS), is being developed by Xcalibur Software, Inc.[21] They are under contract with Naval Facilities Engineering Command (NAVFACENGCOM) for the Interagency Cost Estimating Group for Hazardous and Toxic Waste Remediation (ICEG)[22]. Development of the HTRW-HCAS was started by professional cost engineers and cost estimators with the ICEG who recognized a need for consistent and comparable environmental cleanup cost data (21).

Currently, HTRW-HCAS only consists of a data module (38). The module has a standard work breakdown structure, site parameters, and cost elements. The intent of the system is to develop a database with standardized cost information on federal environmental cleanup efforts (38). Eventually the system is planned to be expanded into a complete cost estimating system utilizing the information in the data module. The data model is in the development stage. Only six projects from the Corps of Engineers - Omaha District have been loaded as of this thesis (38).

---

[21] Xcalibur Software, Inc. is located in Centerville, VA. Point of Contact for the HTRW-HCAS is either Mr. James Brown or Mr. Robert Price at (703) 815-0656.

[22] The ICEG is a professional cost estimating organization formed in March 1991 (21). The group is composed of cost engineers and cost estimators from various federal agencies including the EPA, DOE, Office of the Secretary of Defense (OSD), US Air Force, US Navy, US Army Corp of Engineers, Department of the Interior, and National Aeronautics and Space Administration (NASA). The ICEG was formed to develop a historical database of environmental costs and environmental cost estimating methodologies. For further information on the ICEG contact Mr. Thomas Hurley, Naval Engineering Facilities Command, (703) 325-0036.

The second data base identified was developed by the Independent Project Analysis (IPA) Corporation[23] for the development of its HAZRISK® model. The database contains information from 150 separate EPA, DOE, and private sector sites[24]. The data was used to develop parametric regression equations for cost, schedule, and contingency (cost and schedule) estimating.

IPA was not willing to release the data to representatives from either the EPA or DOE (21). This source of data was not pursued any further because of the company's reluctance to release the data to these federal agencies.

Wang Based Information Management System - Environmental Subsystem (WIMS-ES). One database which is in existence that includes usable cost data is the WIMS-ES system. The DERA module of WIMS-ES contains information on DERA funding and site status. The purpose of the DERA module is to manage and track DERA funds by site and project requirements (35:2). The system also provides management with quick access to DERA funding status and provides the ability to transfer data among different organizations.

The records are maintained at each major command and sometimes at base level and can be reviewed by anyone with

---

[23] IPA Corp is located at 1840 Michael Faraday Drive, Suite 100, Reston, VA 22090, telephone (703) 709-0777.

[24] Private sector means any CERCLA site, privately or publicly owned, for which neither the federal nor a state government is responsible for cleanup.

access to the system. A WIMS-ES record contains fields for information about a site's requirements, status, contract actions, and funding (35:2).

The WIMS-ES database was accessed through terminals at the AFIT School of Civil Engineering and Services (SOCES). RI/FS records in the database were examined to determine the original cost estimate, the final cost, and changes to the project. Also, we were interested in determining if the database contained narrative explanations for deviations between original estimates and final costs, and reasons for changes to projects.

After reviewing the database, two facts became apparent. First the database was extensive. There are over 7347 records and 128 data fields per record (34). Second, most of the data fields were empty[25]. Rather than going through the entire database screen by screen, the search was narrowed. Using the DERA dictionary, fields were selected that appeared to contain the information needed. Captain William Irwin, the SOCES Wang system manager, downloaded those fields onto a floppy disk as a text file. The text file were converted into a Microsoft Excel spreadsheet file[26]. The spreadsheet allowed quick scans of the records.

[25]The WIMS-ES database is only two years old, and many of the users of the system have not yet been able to update the system.

[26]The data was converted into a spreadsheet using the Excel "Parse" command.

Quantification of uncertainty could not be done with the WIMS-ES data for three reasons. First, many of the records contained multiple sites and OUs. The cost for the project was an aggregation of the site and OU costs. Costs could not be broken out between the different sites and OUs. Second, the data was not broken out in sufficient detail. The WIMS-ES system provides data at a macro level. Even if a record contained an OU, the site details were limited or did not exist. Third, the remarks field did not contain detailed information on why the original estimate (the validated amount) deviated from the current working estimate (the amount currently estimated to complete the work)[27]. While the WIMS-ES database did provide useful top level data, it did not contain sufficient detailed information for developing a model for quantifying uncertainty.

Database Development

After concluding that the WIMS-ES system did not provide adequate detailed information, research efforts were then directed towards the development of a database. To get the level of detail required we needed to contact and visit several locations[28]. The search was limited to

[27]Programmed Amount and Current Working Estimate are specific fields within the WIMS-ES system.

[28]Telephone interviews with each base was considered; however, 6 years of experience between the authors of this thesis in budget and cost estimating led us to believe that telephone or written interviews are usually not satisfactory when attempting to understand another persons estimate and the reasons for changes in the estimate. Personal interviews

Headquarters Air Combat Command (ACC) and U.S. Army Corps of Engineers - Omaha District in the interest of time and resources. Visiting individual bases was prohibitive due to time and cost constraints.

Air Combat Command (ACC). To avoid multi-site visits, we contacted Mr. Robert Moore, Chief Restoration Branch, Headquarters Air Combat Command (ACC) and discussed the type of data we required[29]. Mr. Moore advised us that his branch had the information required. We scheduled a site visit for June 14-16, 1993.

After reviewing the data from the WIMS-ES database, we identified 37 ACC RI/FS projects which appeared to have changed (increased or decreased) from the programmed amount (the validated estimate), to the current working estimate (the amount of funding required to complete the effort). We interviewed ACC Program Managers (PgMs)[30] and discussed the causes of differences between the original programmed amount and the current working estimate. Documents reviewed during the interviews included the Narrative Documents[31], the ACC

---

are the best method to fully understand the breakdown of costs, the elements of cost, and the assumptions of a cost estimate.

[32]Headquarters ACC has a large centrally managed program. Captain Robert Wilson, one of the advisors to this thesis, suggested we start with ACC due to the availability of site data.

[30]Program Managers at ACC are responsible for the implementation of IRP projects at specific ACC bases. They are the ACC's direct point of contact for all IRP activities at a base.

[31]A Narrative Document is the document used to request DERA funding for PA, SI, RI,FS. and RD portion of the IRP process.

cost estimate, and notes from individual ACC PgMs files. Our interviews were intended to answer three questions.

1. Why is there a difference between the original programmed amount and the current working estimate?

2. How was the programmed amount in the WIMS-ES system estimated?

3. What caused changes in the requirement?

The interviews revealed the two items which helped explain changes in the funding requirements. First, projects were negotiated at prices higher than the estimates. Major commands, such a ACC, have the authority to redistribute funds from one project to another to cover cost increases of less than 20 percent of the validated programmed amount or less than $200,000 (5:101-102). This means that contracts can be negotiated 20 percent more than the programmed amount (the current budget for the program) without requesting additional funding. This flexibility assumes an equal amount of funding will be available from overestimated projects to cover underestimated projects. Second, the environmental regulators changed the program requirements. This often occurred when the project was delayed. In other words, if the regulator had "time to think about the project," they would ask for additional information or data.

Although PgMs had intimate knowledge of bases they were responsible for, the actual contracting and detailed cost

data on RI/FS is available only at the service centers. Most of the information program managers had came from their service center counterparts. To obtain detailed cost data, we conducted a site visit to the US Army Corps of Engineers, Omaha District.

US Army Corps of Engineers - Omaha District (COE). A total of 47 projects were selected from the WIMS-ES database for review at the COE. Projects that contained either a fire training pit or a land fill were randomly chosen. Both of these types of sites are commonly found at Air Force bases. Projects are dated from fiscal year 1987 through fiscal year 1992.

ACC sent a list of sites we were interested in to the COE. They gathered appropriate contract documents for our review. Air Force project numbers do not match with COE contract numbers. From the 47 projects selected from WIMS-ES, 33 contract files were available to us. There is essentially no correlation between COE contracts and ACC projects. Of the original 47 projects, 15 were done by a different service center and four were not yet contracted. Simple mathematics would say that there should be a total of 28 contracts, 47 - (15 + 4) = 28. However, several of the projects were split between multiple contracts and several projects were combined into a single contract. The total number of contract files made available to us upon arrival was 33. We did not review two contracts because of time

constraints. This left a total of 31 contracts to review. These contracts represented a total of ten bases, seven operating primarily fighters and three operating primarily heavy bombers. The contracts reviewed contained more information than just the projects selected. Multiple projects were combined into one contract and many of the contracts included additional projects that were not requested.

Due to the size of the contract documents, ranging from approximately 400 to 1600 pages per contract, the information was condensed. After reviewing two of the contracts, we limited our data gathering to the following documents:

1. The government's original cost estimate.

2. The final negotiated contract costs, broken out by tasks.

3. Record of Negotiations, a narrative description of the contact negotiations.

4. Scope of Services - A document which describes work to be performed by the contractor.

We limited the data search to these documents because they provided a detailed description of the work to be performed, the COE's original estimate and assumptions, the final negotiated cost, and an explanation of the differences between the COE's original estimate and the final negotiated price.

We also obtained copies of the base Management Action Plan (MAP). The MAP is a comprehensive summary document of an installation's environmental program (5:123). MAPs provided detailed information on each installation's sites and OUs and how they were related. For example, the MAP for Hamilton AFB might describe how sites X,Y, and Z moved from OU-1 to OU-2.

Data obtained from the 31 contract files and ten MAPs became the core of our database. Two facts became apparent during the contracts review.

First, the COE does their own estimate independent of the validated amount - the base estimate which is validated and approved by the major commands and the Air Staff. Unless the COE and Air Force interact at the working level, their estimates are independent. There is no formal structure for reconciling the two estimates.

Second, the COE and Air Force estimate RI/FS efforts at different levels. The Air Force estimates at the site and OU level, while the COE estimates at the contract level. The COE will identify those upcoming contract efforts for a particular base and combine those efforts into one contract[32]. The COE achieves economies of scale by combining RI/FS efforts. For example, field work is less

[32]The COE negotiates Indefinite Deliverables contracts in advance, and exercise contract options as work is added to the contract.

because the contractor can combine trips to the Air Force base instead of making one trip per site or OU.

We reviewed the documents from each contract and synthesized the following information:

1. Negotiated price broken out by both major cost elements (e.g. direct labor) and level of effort (e.g. report writing and analysis).

2. COE estimate broken out by major cost elements.

3. Number of borings and monitoring wells required.

4. Depth of the borings and wells to be completed.

5. Number of samples and analysis taken from each boring or monitoring well.

6. Types of analysis to be done. For example, test for lead in a ground water sample.

7. Reports to be provided by the contractor. Most of the reports, such as the Health and Safety Plan, are required by CERCLA.

Data Standardization. Information obtained from the contracting documents needed to be standardized before developing a cost model. The contracts aggregated multiple sites or OUs. However, since OUs vary from base to base the site was chosen as the standardized unit.

Review of the contract documents showed that eight of the 33 contracts were not really RI/FS efforts. Three contracts were hydrology surveys. One contract was a Preliminary Assessment/Site Investigation (PA/SI). The other four contracts were RI/FS work plans. This left a total of

23 contracts, which contained 60 sites between them. After defining the cost model variables, we eliminated an additional eight contracts due to insufficient data of cost model variables. This left the database with 13 contracts, which contained 49 RI/FS sites between them.

We initially attempted to get only projects with fire training pits or land fills. However, due to COE contracting methods, the data included information on fire pits, land fills, spill site areas, waste pits, and storage tanks. Sufficient data was not available to build a model for any specific type of site. We began development of RI/FS cost factors for RI/FS sites in general. The next section discusses the development of the RI/FS cost model and the cost intervals.

Model Development

This section describes the development of the cost model between RI/FS project costs and various investigative field work activities. The objectives of this research were to develop a cost model to predict the cost and to determine a cost range for performing RI/FS at Air Force sites.

Regression Methodology. This section describes the methodology used to derive the RI/FS cost model. The following steps were used in the development of the model. A separate section is included for each step.

Step 1: Regression Cost Model Assumptions. Discussion of the assumptions used in identifying the causal drivers of the dependent variable RI/FS cost.

Step 2: Identification of Cost Driver Variables. Identification and definitions of the cost driver variables. The objective of this step is to identify which variables logically cause RI/FS costs.

Step 3: Data Normalization. Discussion of the method used to allocate contract costs to individual RI/FS sites and the normalization of data into common base year dollars.

Step 4: Specification of the Model. Specification of relationship between the dependent variable and independent variables. This step incorporates the logic developed in the identification step into the regression model.

Step 5: Cost Model Regression Methodology. Initial analysis of the regression results to ensure the proper specification of the hypothesized model and to ensure that the developed logic has not been violated. If necessary, the required transformations will be accomplished on the independent variables.

Step 6: Diagnostics on the Regression Results. Diagnostic tests used to check the validity of the model include scatter and residual plots, model and independent variable statistical significance, multicollinearity, outlier observations, and normality of the error term residuals.

Regression Cost Model Hypotheses (Step 1). There were two hypotheses in the development of the RI/FS project cost model. The first hypothesis was that the number of required chemical analyses on site samples is the main driver of project costs. The second hypothesis was that the level of effort required to obtain the site samples also drives RI/FS project costs.

The number of required analyses affects most of the activities in a RI/FS project. The more analyses required for a site increases the tasks performed in a RI/FS project. As the work performed for these tasks increases, costs of the RI/FS project increase.

There are two factors that affect the number of required analyses. The first factor is the suspected types of contamination and the second factor is the size of the site. The effect of these factors on the number of required analysis is discussed in the following paragraphs.

The suspected types of contamination affect the number of analyses. The logic behind this was that to determine whether a site requires remedial action, samples from the site must be analyzed for contaminants. The number of

analyses accomplished on the samples depends on the specified types of contaminants that are investigated. The greater the types of suspected contaminants, the greater the number of required analyses.

Site size also affects the number of required analyses. Sites with a type of suspected contamination which are larger in area or volume than other sites with the same type of suspected contamination, require more sampling locations to completely characterize the site. More sampling locations results in more samples. This in turn increases the number of required sample analyses in a RI/FS project with all other factors held constant.

The second hypothesis was that the level of effort required to obtain the site samples is another driver of RI/FS project costs. Level of effort includes the actions and operations that occur during the collection of field samples. Typical actions include planning of the work site, mobilizing workers and equipment to the site, and drilling wells to obtain samples for analyses. The logic was that the more analyses required, the greater the level of effort required to collect samples for analysis.

To fully explore these hypotheses, the different tasks of RI/FS were investigated to provide the link between the two hypotheses and each task. The sources for the task descriptions are a Draft Copy of the "Environmental Pricing Guide for FY94 Programs" and "Scope of Services" documents.

The "Environmental Pricing Guide for FY 94 Programs" is being developed by the Corps of Engineers for program managers to help prepare more accurate cost estimates for project funding purposes (20). In this document, the various activities of the IRP process are identified and categorized into different tasks. The format or grouping of activities closely follows the format of the "Scope of Services" documents. The information provided in this document includes applicable regulations, required work plans and reports, and specific sampling activities that are to take place at each environmental site. The task descriptions that pertain to RI/FS and the link to the number of analyses are work plans, field investigations, data evaluations, reports, and meetings (20:1-2). Each of these is discussed below.

1. Plans. This task includes the development of the various plans for the required activities at RI/FS sites. The different types of plans are work plans, sampling and analysis plans, quality assurance project plans, health and safety plans, and community relations plans (15:C-3). Our assumption was that the number of analyses drives the level of effort for this task. For example, the sampling and analysis plan not only describes the procedures to use when gathering samples, but also the quantity and location of the samples. The number of analyses required, drives the number of samples required, which drives the number of sampling and

analysis plans that must be described and documented. The more sampling plans required increases the level of effort for this task.

2. Field Investigations. This task includes site surveys and mapping, soil boring and monitoring well installation, laboratory analysis of field samples (soil, water, and sediment samples), soil gas surveys, and geophysical tests. The laboratory analysis involves the testing of the field samples for different types of contamination such as oil and grease, fuel, pesticides, dioxins, and metals. There is a direct relationship between the number of required analyses and the level of effort for this task. The number of analyses drives the number of required samples. The number of required samples drives the number and/or depth of soil borings and/or well installations. This in turn drives the level of effort for this task.

3. Data Evaluations. Data evaluations include review of laboratory data and procedures, compilation of data, and verification of data for accuracy and reliability. There is a direct relationship between the number of required analyses and the level of effort for this task. The number of analyses drives the quantity of data that must be verified and compiled into a report.

4. Reports. Activities in this task include the preparation of draft copies and final reports that document

the site characterization field activities and analyses (15:3-29). There is a strong link between the number of required analyses and the level of effort required for this task. The more analyses accomplished, the larger the amount of data that must be analyzed and incorporated into the required reports.

5. Meetings. This includes meetings between contractors, regulatory agencies, servicing agencies, and base representatives to approve work plans, report progress at RI/FS sites, and report draft reviews. The number of analyses directly affects the amount of time spent on these activities. For example, as the required analyses increase, work plans must describe additional procedures to gather more samples for analysis.

To summarize the regression cost model hypotheses again, more required analyses and/or greater level of effort will drive increased RI/FS costs.

Identification of Cost Driver Variables (Step 2). The objective of this step was to identify the major cost driver variables of RI/FS project costs. The variables should incorporate the developed hypotheses. The identified variables should thus represent the number of analyses accomplished during a RI/FS or be related to the level of effort expended in the collection of RI/FS site samples. Two sources of information were used to identify cost drivers. The first source was the Management Action Plans

(MAP) that were prepared for each base. The MAPs provide a summary of the status of environmental restoration and compliance programs (39:1-1). The "Scope of Services" is the second source of information. As stated before, the "Scope of Services" describes the required activities that are to be completed for a RI/FS.

Based on the review of these two sources, six likely variables were identified. These variables were soil analysis, water analysis, sediment analysis, total boring depth, total monitoring well depth, and a categorical variable. The variables were then classified into groups which represent either analyses or level of effort. To represent the number of analyses three variables were chosen. They were the specified number of chemical analyses on the soil, water, and sediment samples. The identified variables selected to represent the level of effort were the total boring depth and total monitoring well depth that were specified for each RI/FS project site. The total soil boring depth variable was derived by summing the product of the number of soil borings per site times the drilling depth specified for each boring. The total monitoring well depth variable is derived by the same procedure. The last variable is a categorical variable to distinguish between complete Remedial Investigation/Feasibility Study sites from Remedial Investigation (RI) sites. This distinction is necessary because the Feasibility Study phase of RI/FS

projects involves the additional activities of developing and screening the possible remediation alternatives (15:1-7). For this reason, RI/FS projects incur more costs than RI projects. All the sites in the data base included chemical analyses and some type of drilling activity. The use of these variables enables the comparison of the sites in the data base to one another. This permits the development of a cost model of RI/FS projects.

Definitions of Variables Selected

Soil Analyses - number of soil samples gathered and analyzed for contaminates.

Water Analyses - number of surface and ground water samples gathered and analyzed for contaminates.

Sediment Analyses - number of sediment samples gathered and analyzed for contaminates.

Analysis - The sum of soil, water, and sediment analyses.

Soil Bore Depth - total soil bore depth for a site measured in linear feet. Derived by summing the drilling depths of all the soil borings at a site.

Groundwater Well Depth - total well depth for a site measured in linear feet. Derived by summing the drilling depths of all the wells at a site.

Categorical Variable - Assigned a value of 0 if RI project, assigned a value of 1 if RI/FS project.

Data Normalization (Step 3). The data for the cost model was collected from two sources. Project prices were obtained from the final Corps of Engineers negotiated contracts. The quantities of samples for analyses and the

drilling depths were determined from the Scope of Services. The individual site costs were derived from thirteen negotiated contracts. The number of sites per contract ranged from one to 15 sites. The contracts generally showed the allocation of field activity costs to individual sites, but not all the costs in a contract were allocated to individual sites. These remaining costs were distributed to sites using a weighted average of individual site samples divided by the total number of samples specified in the contract. The rational for this allocation of costs was our belief that the number of required analyses is the main driver of RI/FS costs. Costs of activities that were allocated included base map updates, site safety and health plans, literature searches, travel, meetings, data validation and evaluation, and mobilization/demobilization costs.

Another problem with the data was the specification of some site activities in more than one contract. For example, the work plans for sites one and two were in one contract, while the field activities were in a different contract. In this case, costs had to be reconciled into the proper sites to derive total RI or RI/FS costs per site.

The final adjustment to the data was the normalization of project costs into common base year dollars to negate the effects of inflation. The years of the contracts ranged from 1987 to 1992. Project costs were normalized into 1991

base year dollars using the OSD price indices contained in ENVEST™, Version 1.5.

Specification of the Model (Step 4). An artificial variable, designated *analysis*, was created by summing the number of soil, water, and sediment samples collected for analysis per site. The three variables were grouped into one artificial variable because the analyses on these samples are often for the same type of contamination. The same price is normally charged for the same chemical analysis no matter the type of sample (20:4). The form of the first specified model is:

$$TC = b_0 + b_1D + b_2X_1 + b_3X_2 + b_4X_3$$

Where: TC = Total RI/FS or RI site costs, 1991 $
b_0, b_1, b_2, b_3, b_4 = Equation coefficients
X_1 = Total samples for analyses per site
X_2 = Total soil boring depth per site
X_3 = Total monitoring well depth per site
D = Categorical variable
(if D=0, then RI site)
(if D=1, then RI/FS site)

The *analysis, boring depth* and *well depth* variables were hypothesized to have an increasing at a decreasing rate relationship with total site costs. The assumption was that there are economies of scale between these variables and site costs; as these variables increase the initial setup and overhead costs of a site are spread over more activities. Initially, the model will be regressed without any transformations on the independent variables. This was

to check if the increasing at a decreasing rate relationships between the variables and total site project cost were evident.

Cost Model Regression Methodology (Step 5). The procedure to check the statistical validity of the model was a sequential process. First, the logic and the specified variable relationships were checked to ensure they have been incorporated into the model. The logic of the model was examined by checking the signs of the independent variables' coefficients. Plots of the residuals verses the independent variables and partial plots were analyzed to ensure the correct specification of the model. Next, the coefficient of determination (R^2), t-statistic and F-value tests were used to evaluate the statistical significance of the model and the regression coefficients. Then plots of the residuals verses the independent variables were analyzed for constant variance of the error terms. Finally, diagnostic tests were performed to evaluate the model for multicollinearity, outlier observations, and normality of the error terms.

Diagnostics of the Regression Results (Step 6). The statistical results of the first model were:

$$TC = b_0 + b_1D + b_2X_1 + b_3X_2 + b_4X_3$$

Where: TC = Total RI/FS or RI site costs, 1991 \$
b_0, b_1, b_2, b_3, b_4 = Equation coefficients
X_1 = Total samples for analyses per site
X_2 = Total soil boring depth per site
X_3 = Total monitoring well depth per site
D = Categorical variable
(if D=0, then RI site)
(if D=1, then RI/FS site)

Were: F Value = 87.216, Adjusted R^2 = .8778, with the statistics shown in Table 2.

Table 2

Model 1 - Statistics

Variable	Coefficient	t Value	Prob > t
Intercept	21600.00	2.537	.0148
D	31456.00	1.727	.0921
Analysis	781.23	6.795	.0001
Boring Depth	-201.37	-2.445	.0185
Well Depth	97.60	4.549	.0001

Regression results of the model indicated the logic of the specified model was not upheld. The *boring depth* variable coefficient is negative. This implied that as the total depth of soil borings increased, total costs decreased. This violated the logic of the specified model. The signs of the remaining variables were positive. The positive signs indicate that as the number of analyses and

the drilling depths increased, total cost increased. This agreed with the general logic of the specified model.

An analysis of the variance inflation factor (VIF) indicated that the model suffered from the effects of multicollinearity between the independent variables. The VIF for the *analysis* and *boring depth* variables were 8.18 and 5.4 respectively. VIF values "considerably larger than one" are indicators of serious multicollinearity problems (29:410). The *analysis* variable definitely was in this problem category and the *boring depth* variable potentially had multicollinearity problems.

The pairwise correlation between the *analysis* and *boring depth* variables was -0.89. This was another indication that the adverse affects of multicollinearity are present in the model.

To counter the effect of multicollinearity that was evident in the first model, the *boring depth* variable was dropped for the next regression run. This was accomplished to see if multicollinearity was a problem with the rest of the model variables. The specified form of the second model was:

$$TC = b_0 + b_1D + b_2X_1 + b_3X_2$$

Where: X_1 = Analysis
X_2 = Total Monitoring Well Depth per Site
D = Categorical variable
(if D=0, then RI site)
(if D=1, then RI/FS site)

Were: F Value = 102.907, Adjusted R^2 = .8643, with the statistics shown in Table 3.

Table 3

Model 2 - Statistics

Variable	Coefficient	t Value	Prob > t
Intercept	22948.00	2.563	.0138
D	54677.00	3.336	.0017
Analysis	530.91	9.625	.0001
Well Depth	118.34	5.698	.0001

The regression results of this model indicated that the logic was upheld; all the independent variables had positive coefficients. The magnitude of the independent variable coefficients appeared to be reasonable. Costs for sample analysis ranged from $15 to $1100 (20:4). The coefficient for the *analysis* variable fell within this range. The magnitude of the coefficient for the *well depth* variable appeared low as compared to the drilling cost per foot of $165 from the Pricing Guide. A possible explanation for this is that the model only had two variables to explain a myriad of factors that drive RI/FS costs. This most likely resulted in coefficient values that will not assume the same values or cost charged to accomplish these activities in RI/FS projects.

The scatter and residual plots for total cost versus *analysis* indicated an increasing at a decreasing rate pattern. This result was not unexpected for the reasons explained in the specification phase of the model development. The scatter and residual plot for total cost verses *well depth* did not indicate any patterns to suggest a departure from a linear relationship between total cost and *well depth*.

The residual plots for both variables were also analyzed for constant variance of the residuals or a homoscedastic pattern (equal error variances). Other than the increasing at a decreasing rate relationship between total cost and the *analysis* variable, no serious departures from a homoscedastic pattern were detected.

The statistical results for this model were significant. The F value of 102.907 indicates that there is a significant regression relationship between the independent variables and the dependent variable. The R^2 was 0.8643 which indicates that the independent variables accounted for 86 percent of the variation in the model. All independent variables were significant at the 95 percent level. The t values indicated that the probability of the slope of the independent variables being zero was highly remote at less than 1 percent for *D*, *analysis*, and *well depth* variables. By dropping the *bore depth* variable, multicollinearity was not a serious problem with the model.

The *analysis* variable had the highest VIF value at 1.695. The pairwise correlation between the *analysis* and *well depth* variable was -0.6159. This value was below the threshold of 0.70. Values above 0.70 indicate that there is a clear trend between the two variables (36:258).

The studentized residuals and the Cook's distance measures were used to check the model for outliers. The studentized residuals test flagged three potential outlier observations. Observation 11 falls into the suspicious category. Observations 12 and 13 can be considered outliers based on studentized residual values of 3.016 and 3.227. The Cook's distance diagnostic measures the influence each observation has on the regression model coefficients. Values of 0.50 or greater are indicators that an observation has substantial influence on the fit of the regression model (29:403). None of the observations in the model had a value greater than 0.181, including the three potential outliers identified by the studentized residual diagnostic test.

The normality of the error terms was examined by a normality plot of the residuals. The residual plots indicated that the assumption of normality might be questionable. An analysis of the possible causes for this potential problem with non normality of the error terms is deferred until our recommended model has been presented.

This model showed that multicollinearity could be dealt with as long as the variables for the *well depth* and the

boring depth were not both in the model. However, the assumption was that to have a valid model, the total depth of the borings, along with the other two variables - the categorical variable *D* and *analysis*, must be included in a RI/FS project. To satisfy this requirement, a new composite variable was created. The new variable, designated *depth*, was derived by summing the total soil boring drilling depth with the total well drilling depth for a project. The *depth* variable now accounted for all the drilling activities that occurred in a project.

The specified form of the third model was:

$$TC = b_0 + b_1D + b_2X_1 + b_3X_2$$

Where: X_1 = Analysis
X_2 = Total Drilling Depth per Site
D = Categorical variable
(if D=0, then RI site)
(if D=1, then RI/FS site)

Were: F Value = 84.386, Adjusted R^2 = .8390,

with statistics shown in Table 4.

Table 4

Model 3 - Statistics

Variable	Coefficient	t Value	Prob > t
Intercept	25839.00	2.666	.0106
D	65139.00	3.534	.0010
Analysis	408.02	5.541	.0001
Depth	109.07	4.506	.0001

This model incorporated the developed logic; all independent variables had positive coefficients. This meant that as the independent variables increased in value, total costs also increased. The magnitudes of the coefficients of the independent variables appeared reasonable.

The scatter and residual plots for the *analysis* variable exhibited an increasing at a decreasing rate relationship with total costs. The partial regression plot of the *analysis* variable was not as conclusive as the other plots, but the increasing at a decreasing rate relationship cannot be ruled out. The *depth* variable also exhibited an increasing at a decreasing rate relationship with total costs, although this trend was not as strong.

Multicollinearity was not a serious factor in this model. The *analysis* variable had the highest VIF at 2.55. The pairwise correlation between the *analysis* and *depth* variables was -0.6165. These results indicate that multicollinearity might still be present, but the affects were not as serious as they were in the first model.

The studentized deleted residual diagnostic for outliers identified the same three observations as outliers that were identified before. Again, the Cook's distance diagnostic test did not identify any influential outliers. A review of the information and data on the three outlier observations did not reveal any unusual or extraneous circumstances.

The normality plot of the residuals indicated that the error terms are distributed in a right skewed distribution. The stem and leaf plot of the error terms also indicated a skewed distribution. Before discussing the potential problems caused by the non normality of the error terms, one more transformation of the independent variables will be attempted.

Based on the examination of the normality, scatter and residual plots the *analysis* and *depth* variables were be respecified. To obtain a linear relationship with total costs and to try to correct the nonnormality of the error terms, the square root transformation of the *analysis* and *depth* variables was attempted.

The specified form of the new model was:

$$TC = b_0 + b_1 D + b_2 X_1 + b_3 X_2$$

Where: X_1 = Square Root (Analysis)
X_2 = Square Root (Drilling Depth per Site)
D = Categorical variable
(if D=0, then RI site)
(if D=1, then RI/FS site)

Were: F Value = 82.218, Adjusted R^2 = .8354, with the statistics shown in Table 5.

Table 5

Model 4 - Statistics

Variable	Coefficient	t Value	Prob > t
Intercept	-69727.00	-4.126	.0002
D	48360.00	2.508	.0158
Analysis	13595.00	6.414	.0001
Depth	3144.50	3.707	.0006

The regression results of this model indicated that the desired logic of the independent variables was maintained. The logic of the *analysis* and *depth* variables was that as the number of analyses and the total drilling depth increased, total costs would increase. The negative value of the intercept was a problem for sites that require a low number of sample analyses. In fact, the predicted value for observation thirty-five was negative. This observation required only one soil boring that had a drilling depth of twenty feet and four samples for analysis.

The scatter and residual plot results for both the *analysis* and *depth* variables appeared to have improved from the previous model. Both scatter plots of the variables versus total costs indicated a linear relationship. Also, both residual plots of the independent variables versus the residuals appeared to exhibit a more definite homoscedastic (constant variance) pattern.

The model was statistically significant with an F value of 82.218 and an adjusted R square of 0.8354. The t values for all the variable coefficients were significant.

Multicollinearity between the independent variables was not a problem. The VIF was 2.61 for the *analysis* variable and 1.59 for the *depth* variable. The pairwise correlation between *analysis* and *depth* was -0.5928.

The same three observations were flagged as potential outliers by the studentized residual diagnostic test, but the Cook's distance test indicated that there were not any influential outliers. The highest Cook's distance value was 0.182 for observation twelve.

The normality plot of the error terms improved from the last model, but the plot still indicated a right skewed distribution of the error terms. The stem and leaf plot confirmed the skewed distribution.

Possible explanations for the departure of normality of the error terms were an inappropriate regression model, too few observations to represent the true population, or error variance was not constant (29:128). With the present models, all three explanations could be possible causes of the departure from normality of the error terms.

The first explanation, an inappropriate regression model, is a possibility because this model only contains two variables to explain a very complicated process. There are many factors that drive RI/FS costs; it is very difficult

to quantify all the factors into regression model variables. Examples of these factors are the complexity of the geologic characteristics of the soil, accessibility of a site, effort required for reports, and prior knowledge of a site. The information collected on the observations in the data base limits the possible development of the independent variables to the variables chosen. Quantification of all the selected variable in the models was straight forward. There was not enough information in the data base to hypothesize any other variables that drive RI/FS project costs.

To support the second explanation, there is a distinct possibility that there were not enough observations in the data set to represent the true population of RI/FS projects. There were forty-nine observations in the regression model, collected from nine bases. There were over four hundred identified sites at these bases for an average of forty-four sites per base. In the United States, there are over ninety active and deactivated Air Force bases (19:133-143). If the average of forty-four sites holds true for all the bases in the Air Force inventory, then the forty-nine observations represent 1.2 percent of the potential number of RI/FS sites. The possibility of not having a true representation of RI/FS projects in the data base cannot be ruled out.

To address the third explanation, it was difficult to determine if the pattern of the error terms in the plot of the error term residuals verses the independent variables

departed from a constant variance or homoscedastic pattern. While there was a distinct possibility that the patterns may be heteroscedastic (error term variance not constant), there were not any definite patterns or trends that suggested that the assumption of constant variance of the error terms must be rejected.

Nonnormality of the error terms affects the statistical tests and interval estimates on the regression model. Significant departures from a normal distribution of the error terms may render confidence intervals and hypothesis tests invalid (29:52). Moderate departures from normality of the error terms do not seriously affect the confidence internals and hypothesis tests (30:534). In a sense, the error terms represent the different factors that effect RI/FS costs that are not explained by the variables in the model (30:534). As stated before, it would be difficult to develop cost driver variables that could account for all the factors that drive RI/FS costs. The regression models developed up to this point may suffer from the effects of missing variables, but the information collected does not present any other alternatives than those already explored. This situation forces the selection of the best model developed so far.

Model Selection. Two models were considered for selection to develop the cost risk quantification factors. The two models are:

Model 3: $TC = b_0 + b_1D + b_2X_1 + b_3X_2$

Where: X_1 = Analysis
X_2 = Drilling Depth per Site
D = Categorical variable
(if D=0, then RI site)
(if D=1, then RI/FS site)

Model 4: $TC = b_0 + b_1D + b_2X_1 + b_3X_2$

Where: X_1 = Square Root (Analysis)
X_2 = Square Root (Drilling Depth per Site)
D = Categorical variable
(if D=0, then RI site)
(if D=1, then RI/FS site)

The criteria used to select the best model included the logic of the model, statistical significance, and proper specification of the independent variables. Based on this criteria, model 3 was selected.

Model 3 maintains the general logic developed in the model building step and all the predicted values were positive throughout the ranges of the independent variables. The logic of model 3 is that as either the number of analyses or the total depth of the borings and wells increase, total costs increase. This logic holds true for either RI/FS or RI projects. Although Model 4 more correctly incorporates our complete logic, the predicted costs at the lower ranges of the independent variables were negative. Observation 35 is an example of this situation.

This observation had one boring drilled to a depth of twenty feet to collect four soil samples for contamination analysis. The predicted cost for this observation was negative $28474. The negative intercept of Model 4 is the cause of this problem.

Beyond this problem with Model 4, there were not any other significant differences between the models. The statistical significance of both models was essentially the same. Model 3's F and R^2 values were 84.386 and 0.8390 verses Model 4's F and R^2 values of 82.218 and 0.8354. Also, there was no difference between the effects of outliers and multicollinearity on either model, both the models' test values were basically the same.

The main difference in the models was in the specification of the independent variables. Both the scatter and residual plots showed a slight trend that indicated a possible increasing at a decreasing rate relationship between the dependent and independent variables. Model 4 incorporated this specification better than Model 3. Despite the slight advantages of Model 4 over Model 3 in regards to the specification and normality of the error terms, the negative intercept caused us to eliminate Model 4.

One final note, the right skewed distribution of the error terms caused the models to predict costs on the low side of true costs. With the final cost model selection

made, the development of the cost interval that accounts for the cost risk in RI/FS projects now may be explored.

Cost Interval Development. The objective of this step was to develop cost intervals that could be applied to a RI/FS cost estimate to account for the uncertainty surrounding the cost estimate. The cost intervals should be calculated over the range of the analyses and the total depth of the borings and wells in the cost model. The cost intervals were developed from the predicted costs of the selected regression model. The procedure used to derive the confidence interval was discussed first. Then the application of the cost factors to RI/FS cost estimates was discussed.

The prediction interval (P.I.) for predicted costs from the model was based on the formula:

$$P.I. = Y_{predict} \pm Z_{\alpha/2} * S_{y'}$$

Where: $Y_{predict}$ = Predicted cost from the cost model
Z = Standard normal variable
α = Confidence level
$S_{y'}$ = Standard error of the predicted cost

The predicted cost was derived from the cost model:

$$\text{Total cost} = b_0 + b_1D + b_2X_1 + b_3X_2$$

Where: X_1 = Analysis
X_2 = Total Drilling Depth per Site
D = Categorical variable
(if D=0, then RI site)
(if D=1, then RI/FS site)

The prediction interval was specified at the 70 percent significance level. This means that the probability of the prediction interval encompassing the true cost is 70 percent, based on the observations used to develop the cost model. The standard error of the predicted cost measures the dispersion or variance of costs around the regression line of the cost model at specific independent variable (X_1 and X_2) values. The formula to derive the standard error of the predicted cost was stated in matrix terms because of the multivariate cost model. The formula for $S_{y'}$ is:

$$S_{y'} = \{S^2_{y.1,2}\ [1 + p^T(X^TX)^{-1}p]\}^{.5}$$

where:

$S^2_{y.1,2}$ = variance of the cost model or the Mean Squared Error (MSE)

p^T = vector of the independent variables for one observation and 1 for the intercept

X^T = Matrix transpose of X

X = Matrix of the all the independent variables in the model and 1 for the intercept

p = column vector of the independent variables and 1 for the intercept

The variance (MSE) of the cost model was taken from the ANOVA table for this model. This model's MSE equals 2,130,325,927.

The X matrix was a 49 * 4 matrix that included the independent variables (*analysis, depth, and D*) plus one for

the intercept for the 49 observations used to develop the cost model. The form of the X matrix was:

observation	1:	1	752	1160	1
observation	2:	1	552	995	1
observation	3:	1	112	340	0
.		.	.	.	.
.		.	.	.	.
.		.	.	.	.
observation	49:	1	72	0	0

The first column represents the intercept of the cost model. Columns two and three are the number of analyses and total depth for each observation. Column four is the categorical variable that indicated whether the observation is a RI/FS or RI project.

The X^T matrix is the transpose matrix of the X matrix. Its form was:

intercept:	1	1	1	...	1
analysis:	752	552	112	...	72
depth:	1160	995	340	...	0
D:	1	1	0	...	0

The p column vector was a 4 * 1 matrix of the independent variables plus one for the intercept. The column vector represents one observation. Its form for the first observation was:

$$\begin{matrix} 1 \\ 752 \\ 1160 \\ 1 \end{matrix}$$

The p^T vector was the transpose matrix of the column vector p. Its form for the first observation was:

$$1 \quad 752 \quad 1160 \quad 1$$

The range between the lower and upper bounds of the confidence interval depends on the specified confidence level, the variance of the regression line, and the distance that the independent variables are from their means in the model. In this situation, the confidence level and the variance around the regression line (cost model) were constant. Only the independent variables varied when the confidence interval was derived throughout the spectrum (varying values of the input variables *analysis*, *depth*, and *D*) of the model.

To derive confidence intervals throughout the spectrum of the cost model, various ranges of the *analysis* and *depth* variables were used. The range of independent variables was based on actual ranges from the database. The value of the *analysis* variable ranged from 0 to 752 for the RI/FS observations and ranged from 0 to 253 for RI observations. The *depth* variable ranged from 0 to 1160 feet for RI/FS observations and ranged from 0 to 1550 feet for RI observations. Confidence intervals were derived separately for the RI/FS and RI projects. The resulting confidence

intervals and predicted costs for the different ranges of independent variables are presented in the tables in Appendices B and C.

Application of Cost Interval Tables. The first two columns in the tables are the ranges and increments of the *depth* and *analysis* variables. The third column is the predicted cost of a project calculated by the cost model using the values of the *depth* and *analysis* variables from the first two columns. The values in the fourth column, which represents the interval value around the predicted cost, is calculated by the prediction interval (P.I.) formula:

$$P.I. = Y_{predict} \pm Z_{\alpha/2} * S_{y}.$$

The fifth and sixth columns represent the lower and upper bounds of the confidence interval around the predicted cost. The lower and upper bounds are calculated by adding or subtracting the interval from the predicted cost.

The following example demonstrates how the first row of table in Appendix B was calculated. The first row is a RI/FS project. Columns one and two are the values of the *depth* and *analysis* variables.

Column 3

$$\text{Predicted Cost} = b_0 + b_1*D + b_2*(\text{Analysis}) + b_3 *(\text{Depth})$$

$$\text{Predicted cost} = 25839 + 65139*(1) + 408.19*(5) + 109.79*(0)$$

$$= 93019 \text{ (rounded off to the nearest unit)}$$

Column 4

Interval = $Z_{\alpha/2} * S_{y'}$

$Z_{\alpha/2}$ = 1.0365 (70 percent confidence level)

$S_{y'} = \{S^2_{y.1,2}\ [1 + p^T(X^TX)^{-1}p]\}^{.5}$

where:

$S^2_{y.1,2}$ = 2,130,325,927

(X^TX) =

49	7136	14315	16
7137	2040156	3524007	4321
14315	3523762	10151999	6075
16	4320	6075	16

$(X^TX)^{1}$ =

0.044093	-8.80E-05	-2.5E-05	-0.01082
-8.8E-05	2.55E-06	-55.2E-07	-0.0004
-2.5E-05	-5.2E-07	2.79E-07	5.98E-05
-0.01083	-0.0004	5.97E-05	0.159479

p^T = 1 5 0 1

p = 1
5
0
1

$p^T*(X^TX)^{1}$ = 0.032827 -0.00048 3.18E-05 0.14664

$[p^T*(X^TX)^{-1}]*p$ = .177078

$S_{y'}$ = [2,130,325,927 * (1+.177078)]^5

$S_{y'}$ = 50075

Interval = $Z_{.15} * S_{y'}$

= 1.0365 * 50075

= 51903

Columns 5 & 6

Lower bound of the P.I. = Predicted Cost - 51903
= 93019 - 51903
= 41116

Upper bound of the P.I. = Predicted Cost + 51903
= 90319 + 51903
= 144922

To apply the cost interval, an estimator derives a RI/FS cost estimate using ENVEST™. Next, the cost prediction interval is extracted from the tables. The required number of analyses and total depth are the inputs for the cost interval tables. The cost estimate is compared to the cost interval. Cost estimates that fall within the prediction interval provide the estimator a reasonableness check of the of his/her estimate. The prediction interval is derived from the cost model, which is developed from a data base of final negotiated contract prices. The interval provides the estimator with a range of contract prices at a specified level of effort and 70 percent confidence level to compare to his/her estimate . Estimates that are within the interval are an indication that the estimate is within the price range of other projects of similar efforts. Estimates that fall outside the interval indicate that the estimate should be investigated for the factors that cause the project estimate to be significantly different from the range of prices of the projects in the data base. The

interval provides a cross check to ensure all factors are accounted for in RI/FS cost estimates made by project managers.

As a heuristic guide to uncertainty and in their cost estimate, the estimator could utilize the range from the tables to generate approximate 70 percent bounds for their cost. Note that bounds thus generated are strictly approximations and that several limitations on their use are discussed in the next chapter.

V. Conclusions and Recommendations

This thesis developed a methodology to account for uncertainty that surrounds Remedial Investigation/Feasibility Studies cost estimates. Initial research revealed that sufficient information was not available to directly quantify areas of uncertainty in RI/FS cost estimates. Detailed cost data did not exist in any centralized database. Development of a database was required. This database contains price data from contracts for RI/FS projects. From the database a cost model and cost prediction intervals were developed. The resulting prediction intervals do not specifically quantify the uncertainty of RI/FS projects. However, the cost intervals do provide a cross check for estimates calculated by the ENVEST™ model.

Research Findings

At the present stage of development there are limitations in the database. First, information used to build the database was from a single source. All cost data were from contracts negotiated by the Army Corps of Engineers - Omaha District. This potentially limits the use of the cost intervals to only estimates from the Omaha District. The F.A.R. contract regulation supplements differ between service centers. Also, the negotiation process and

relationships between the service centers and contractors may be unique to each service center. The database may not accurately reflect contract prices from other service centers.

Another limitation is the database only contains forty-nine RI/FS site data points from thirteen contracts. In addition, eleven site data points are from one contract and twelve site data points are from one another contract. The data points from these contracts may exert too much influence in the model. The database may not fully represent the true population of RI/FS projects.

The last limitation of the database is the method used to allocate costs to individual sites. The method used was a weighted average of required chemical analyses on the site samples. Although it is believed that this method best represents the level of effort for each site, cost distortions are possible.

There are limitations to the cost model used to develop the cost intervals. Use of the model (and cost intervals) is limited to RI/FS projects that only require drilling activities. Work efforts at the sites in the database only involve drilling of borings and wells and collection of samples for analysis. The *depth* variable only accounts for these drilling activities. Sites that required other types of activities were excluded from the model. Examples of the

excluded activities are soil gas surveys, hydropunches, and trenching.

The departure from normality of the error terms in the model is another limitation. This may affect statistical tests of the model and the prediction intervals. Possible causes of this potential problem are an inappropriate regression model, too few observations (data points) to represent the true population of RI/FS projects, or non constant error term variance.

There is a potential problem with the specification of the cost model. The scatter and residual plots of the data from the model show a possible increasing at a decreasing rate relationship between contract costs and *analysis* and *depth* variables. More data points from which to build the model are needed to determine if this type of relationship is correct.

Finally, the use of our bounds as a heuristic for ENVEST™ estimate bounds may be more valid as a concept than as an option using our additive model. Results would generate large percent bounds for small projects and small percent bounds for large projects.

Further Research

This thesis demonstrates the potential of cost models and cost intervals to incorporate cost uncertainty into RI/FS estimates. Future research is required to expand the

database and improve the cost model to eliminate the identified limitations.

Several additional sources should be explored to expand the database. The other service centers should be investigated as sources for cost data. The Hazardous, Toxic, and Radioactive Waste Historical Cost Analysis System (HTRW-HCAS) is collecting actual cost data from IRP projects. One objective of HTRW-HCAS is to have a database of standardized costs. Presently this database contains very little data, but it should be considered a source for future research efforts.

Future research is required to eliminate the identified weaknesses in the cost model. Additional data points are needed to ensure that the true population of RI/FS projects is represented in the model. Other specified forms of the model should be investigated. The model is specified as an additive model, but a multiplicative model should be investigated. The independent variables in the model only account for drilling activities. The data collected for this thesis was the limiting factor in choosing the variables in the cost model. Variables that are more diverse to account for all types of RI/FS field activities should be developed. Variables that represent site size or volume of contamination and the number of different contaminants tested may be necessary.

Research is still needed to identify cost uncertainty in IRP projects. This thesis only contains information on negotiated contract prices. Comparisons of actual RI/FS costs verses estimated cost should be accomplished.

Conclusion

The developed cost model and intervals are based on information obtained from the Army Corps of Engineers - Omaha District. While the thesis did not specifically identify and quantify cost uncertainty, a method was developed to cross check RI/FS project cost estimates. A heuristic method was proposed which might prove useful after further evaluation.

Appendix A: RI/FS Database

ALL SITES

OBS	#	YEAR	TOTAL COST	PRICE INDEX	1991 BY$	BORES	WELLS	SOIL SPL/AN	WATER SPL/AN	SED SPL/AN	BORE DEPTH	WELL DEPTH
1	21/OU1	1992	515290	1.061	485664	22	7	441	240	71	880	280
2	18/OU9	1992	376934	1.061	355263	23	21	255	250	38	575	420
3	23/NDOCK	1992	84263	1.061	79418	6	4	78	34	0	180	160
4	25/OU7	1992	216262	1.061	203828	18	0	247	34	34	180	0
5	25/OU8	1992	243759	1.061	229745	24	4	216	32	0	140	160
6	19/FT16	1990	18924	0.976	19389	20	3	18	10	0	100	60
7	19/FT17	1990	56172	0.976	57553	22	9	64	40	0	88	180
8	19/OT21	1990	38539	0.976	39487	5	2	75	32	0	25	40
9	19/FT23	1990	22411	0.976	22962	8	2	15	34	12	40	40
10	19/LF6	1990	20916	0.976	21430	10	2	21	20	0	40	40
11	13/FT05	1990	147861	1.019	145104	4	0	15	51	0	4	0
12	13/FT04	1992	106552	1.019	104565	3	0	12	75	0	3	0
13	3/FT01	1992	401320	1.061	378247	8	6	162	79	16	120	270
14	7/LF1	1990	271986	0.976	278674	0	3	40	148	0	0	1550
15	7/LF2	1990	112263	0.976	115024	0	0	80	0	0	0	0
16	29/SD12	1992	157097	1.061	148065	7	0	132	0	0	80	0
17	29/SD27	1992	76502	1.061	72104	0	0	36	0	28	0	0
18	29/FT08	1992	122803	1.061	115743	4	0	130	0	0	0	0
19	1/OU9	1992	151628	1.061	142910	3	3	78	54	12	46	165
20	1/OU9	1992	243002	1.061	229031	5	4	106	103	20	66	250
21	2/OU5	1992	292768	1.061	275936	8	5	159	108	0	120	125
22	2/OU5	1992	409883	1.061	386318	5	12	108	154	0	100	800
23	2/OU7	1992	180902	1.061	170501	8	3	64	78	0	280	115
24	2/OU7	1992	293083	1.061	276233	8	3	128	107	0	200	75
25	27/LF01	1990	153486	0.976	157260	0	0	0	167	0	0	0
26	27/WP17	1990	17708	0.976	18143	2	0	15	0	0	40	0
27	27/WP24	1990	54606	0.976	55948	6	0	63	0	0	60	0
28	27/LF02	1990	110564	0.976	113283	0	3	0	43	0	0	400
29	27/LF03	1990	105682	0.976	108281	0	3	0	33	0	0	600
30	27/FT18	1990	43406	0.976	44473	1	0	54	0	0	30	0
31	27/FT19	1990	203539	0.976	208544	8	0	253	0	0	240	0
32	27/FT20	1990	39407	0.976	40376	6	0	41	0	0	30	0

Appendix A: RI/FS Database

ALL SITES

OBS	#	YEAR	TOTAL COST	PRICE INDEX	1991 BY$	BORES	WELLS	SOIL SPL/AN	WATER SPL/AN	SED SPL/AN	BORE DEPTH	WELL DEPTH
33	27/WP23	1990	81629	0.976	83636	3	0	95	0	0	90	0
34	27/LF1/2	1990	154862	0.976	158670	0	3	0	40	0	0	850
35	27/SD04	1990	5500	0.976	5635	1	0	4	0	0	20	0
36	27/FT05	1990	72680	0.976	74467	6	0	80	0	0	90	0
37	31/LF02	1987	138852	0.875	158688	0	2	0	68	0	0	730
38	31/FT03	1987	137491	0.875	157133	5	1	138	32	0	300	365
39	31/FT04	1987	17425	0.875	19914	2	0	55	0	0	120	0
40	31/SD19	1987	17663	0.875	20186	1	0	31	0	0	60	0
41	31/SD20	1987	20692	0.875	23646	1	0	33	12	0	15	0
42	31/SD21	1987	20692	0.875	23646	1	0	33	12	0	15	0
43	31/ST35	1987	72600	0.875	82971	4	0	146	0	0	240	0
44	31/ST36	1987	72600	0.875	82971	4	0	146	0	0	240	0
45	31/OT37	1987	191103	0.875	218403	4	1	166	42	0	360	365
46	31/ST38	1987	34002	0.875	38774	3	0	50	0	0	180	0
47	31/OT40	1987	32767	0.875	37446	2	0	58	0	0	100	0
48	18/OU12	1992	351686	1.061	331478	10	10	250	153	86	400	300
49	29/SD25	1992	8528	1.061	85323	0	0	0	32	48	0	0

Appendix B:

RI/FS COST INTERVALS

DEPTH	ANALYSIS	COST	INTERVAL	LOW	HIGH
0	5	93019	51903	41116	144922
0	25	101183	51503	49680	152686
0	50	111388	51062	60326	162450
0	75	121592	50689	70903	172281
0	100	131797	50386	81411	182183
0	125	142002	50154	91848	192156
0	150	152207	49993	102214	202200
50	25	106672	51566	55106	158238
50	50	116877	51096	65781	167973
50	75	127082	50695	76387	177777
50	100	137287	50362	86925	187649
50	125	147491	50100	97391	197591
50	150	157696	49909	107787	207605
100	25	112162	51660	60502	163822
100	50	122367	51162	71205	173529
100	75	132571	50732	81839	183303
100	100	142776	50370	92406	193146
100	125	152981	50080	102901	203061
100	150	163186	49858	113328	213044
150	25	117651	51784	65867	169435
150	50	127856	51259	76597	179115
150	75	138061	50800	87261	188861
150	100	148266	50409	97857	198675
150	125	158470	50088	108382	208558
150	150	168675	49838	118837	218513

Appendix B:

RI/FS COST INTERVALS

DEPTH	ANALYSIS	COST	INTERVAL	LOW	HIGH
200	25	123141	51939	71202	175080
200	50	133346	51387	81959	184733
200	75	143550	50900	92650	194450
200	100	153755	50480	103275	204235
200	125	163960	50130	113830	214090
200	150	174165	49850	124315	224015
250	25	128630	52125	76505	180755
250	50	138835	51545	87290	190380
250	75	149040	51030	98010	200070
250	100	159245	50582	108663	209827
250	125	169449	50203	119246	219652
250	150	179654	49894	129760	229548
250	175	189859	49657	140202	239516
250	200	200064	49492	150572	249556
250	225	210268	49400	160868	259668
250	250	220473	49382	171091	269855
250	275	230678	49438	181240	280116
300	25	134120	52340	81780	186460
300	50	144325	51734	92591	196059
300	75	154529	51192	103337	205721
300	100	164734	50716	114018	215450
300	125	174939	50308	124631	225247
300	150	185144	49970	135174	235114
300	175	195348	49703	145645	245051
300	200	205553	49509	156044	255062
300	225	215758	49387	166371	265145
300	250	225963	49339	176624	275302
300	275	236167	49365	186802	285532

Appendix B:

RI/FS COST INTERVALS

DEPTH	ANALYSIS	COST	INTERVAL	LOW	HIGH
350	25	139609	52584	87025	192193
350	50	149614	51952	97662	201766
350	75	160019	51384	108635	211403
350	100	170224	50881	119343	221105
350	125	180428	50445	129983	230873
350	150	190633	50078	140555	240711
350	175	200838	49782	151056	250620
350	200	211043	49557	161486	260600
350	225	221247	49406	171841	270653
350	250	231452	49328	182124	280780
350	275	241657	49323	192334	290980
350	300	251862	49393	202469	301255
400	25	145099	52858	92241	197957
400	50	155304	52201	103103	207505
400	75	165508	51606	113902	217114
400	100	175713	51076	124637	226789
400	125	185918	50613	135305	236531
400	150	196123	50217	145906	246340
400	175	206327	49892	156435	256219
400	200	216532	49638	166894	266170
400	225	226737	49457	177280	276194
400	250	236942	49349	187593	286291
400	275	247146	49314	197832	296460
400	300	257351	49354	207997	306705
450	25	150588	53160	97428	203748
450	50	160793	52478	108315	213271
450	75	170998	51858	119140	222856
450	100	181203	51302	129901	232505
450	125	191407	50811	140596	242218
450	150	201612	50388	151224	252000
450	175	211817	50034	161783	261851
450	200	222022	49751	172271	271773
450	225	232226	49540	182686	281766
450	250	242431	49402	193029	291833
450	275	252636	49337	203299	301973
450	300	262841	49347	213494	312188

Appendix B:

RI/FS COST INTERVALS

DEPTH	ANALYSIS	COST	INTERVAL	LOW	HIGH
500	25	156078	53490	102588	209568
500	50	166283	52785	113498	219068
500	75	176487	52140	124347	228627
500	100	186692	51558	135134	238250
500	125	196897	51040	145857	247937
500	150	207102	50950	156152	258052
500	175	217306	50208	167098	267514
500	200	227511	49896	177615	277407
500	225	237716	49655	188061	287371
500	250	247921	49488	198433	297409
500	275	258125	49393	208732	307518
500	300	268330	49372	218958	317702
500	325	278535	49425	229110	327960
500	350	288740	49552	239188	338292
500	375	298944	49751	249193	348695
500	400	309149	50023	259126	359172
500	425	319354	50365	268989	369719
550	100	192182	51843	140339	244025
550	125	202386	51299	151087	253685
550	150	212591	50822	161769	263413
550	175	222796	50412	172384	273208
550	200	233001	50072	182929	283073
550	225	243205	49802	193403	293007
550	250	253410	49605	203805	303015
550	275	263615	49481	214134	313096
550	300	273820	49430	224390	323250
600	100	197671	52157	145514	249828
600	125	207876	51588	156288	259464
600	150	218081	51084	166997	269165
600	175	228285	50647	177638	278932
600	200	238490	50279	188211	288769
600	225	248695	49981	198714	298676
600	250	258900	49755	209145	308655
600	275	269104	49601	219503	318705
600	300	279309	49520	229789	328829

Appendix B:

RI/FS COST INTERVALS

DEPTH	ANALYSIS	COST	INTERVAL	LOW	HIGH
650	100	203161	52500	150661	255661
650	125	213365	51906	161459	265271
650	150	223570	51376	172194	274946
650	175	233775	50913	182862	284688
650	200	243980	50517	193463	294497
650	225	254184	50191	203993	304375
650	250	264389	49935	214454	314324
650	275	274594	49752	224842	324346
650	300	284799	49642	235157	334441
650	325	295003	49605	245398	344608
650	350	305208	49641	255567	354849
650	375	315413	49750	265663	365163
650	400	325618	49933	275685	375551
700	100	208650	52870	155780	261520
700	125	218855	52252	166603	271107
700	150	229060	51697	177363	280757
700	175	239264	51208	188056	290472
700	200	249469	50785	198684	300254
700	225	259674	50431	209243	310105
700	250	269879	50147	219732	320026
700	275	280083	49935	230148	330018
700	300	290288	49795	240493	340083
700	325	300493	49728	250765	350221
700	350	310698	49735	260963	360433
700	375	320902	49814	271088	370716
700	400	331107	49967	281140	381074
700	425	341312	49967	291345	391279
700	450	351517	49967	301550	401484
700	475	361721	49967	311754	411688

Appendix B:

RI/FS COST INTERVALS

DEPTH	ANALYSIS	COST	INTERVAL	LOW	HIGH
750	100	214140	53268	160872	267408
750	125	224344	52627	171717	276971
750	150	234549	52047	182502	286596
750	175	244754	51532	193222	296286
750	200	254959	51083	203876	306042
750	225	265163	50702	214461	315865
750	250	275368	50390	224978	325758
750	275	285573	50149	235424	335722
750	300	295778	49980	245798	345758
750	325	305982	49884	256098	355866
750	350	316187	49860	266327	366047
750	375	326392	49910	276482	376302
750	400	336597	50032	286565	386629
750	425	346801	50227	296574	397028
750	450	357006	50493	306513	407499
750	475	367211	50830	316381	418041
800	100	219629	53693	165936	273322
800	125	229834	53029	176805	282863
800	150	240039	52425	187614	292464
800	175	250243	51885	198358	302128
800	200	260448	51410	209038	311858
800	225	270653	51002	219651	321655
800	250	280858	50662	230196	331520
800	275	291062	50394	240668	341456
800	300	301267	50197	251070	351464
800	325	311472	50071	261401	361543
800	350	321677	50018	271659	371695
800	375	331881	50035	281846	381916
800	400	342086	50130	291956	392216
800	425	352291	50295	301996	402586
800	450	362496	50531	311965	413027
800	475	372700	50838	321862	423538
800	500	382905	51214	331691	434119

Appendix B:

RI/FS COST INTERVALS

DEPTH	ANALYSIS	COST	INTERVAL	LOW	HIGH
850	100	225119	54144	170975	279263
850	125	235323	53457	181866	288780
850	150	245528	52831	192697	298359
850	175	255733	52266	203467	307999
850	200	265938	51766	214172	317704
850	225	276142	51332	224810	327474
850	250	286347	50966	235381	337313
850	275	296552	50670	245882	347222
850	300	306757	50443	256314	357200
850	325	316961	50289	266672	367250
850	350	327166	50206	276960	377372
850	375	337371	50196	287175	387567
850	400	347576	50259	297317	397835
850	425	357780	50394	307386	408174
850	450	367985	50600	317385	418585
850	475	378190	50878	327312	429068
850	500	388395	51225	337170	439620
900	100	230608	54621	175987	285229
900	125	240813	53912	186901	294725
900	150	251018	53263	197755	304281
900	175	261222	52675	208547	313897
900	200	271427	52151	219276	323578
900	225	281632	51691	229941	333323
900	250	291837	51299	240538	343136
900	275	302041	50975	251066	353016
900	300	312246	50721	261525	362967
900	325	322451	50537	271914	372988
900	350	332656	50426	282230	383082
900	375	342860	50386	292474	393246
900	400	353065	50419	302646	403484
900	425	363270	50525	312745	413795
900	450	373475	50701	322774	424176
900	475	383679	50949	332730	434628
900	500	393884	51266	342618	445150

Appendix B:

RI/FS COST INTERVALS

DEPTH	ANALYSIS	COST	INTERVAL	LOW	HIGH
950	100	236098	55122	180976	291220
950	125	246302	54393	191909	300695
950	150	256507	53722	202785	310229
950	175	266712	53111	213601	319823
950	200	276917	52562	224355	329479
950	225	287121	52078	235043	339199
950	250	297326	51660	245666	348986
950	275	307531	51309	256222	358840
950	300	317736	51027	266709	368763
950	325	327940	50816	277124	378756
950	350	338145	50676	287469	388821
950	375	348350	50607	297743	398957
950	400	358555	50611	307944	409166
950	425	368759	50686	318073	419445
950	450	378964	50833	328131	429797
950	475	389169	51051	338118	440220
950	500	399374	51339	348035	450713
950	525	409578	51696	357882	461274
950	550	419783	52120	367663	471903
1000	100	241587	55647	185940	297234
1000	125	251792	54898	196894	306690
1000	150	261997	54206	207791	316203
1000	175	272201	53573	218628	325774
1000	200	282406	53001	229405	335407
1000	225	292611	52492	240119	345103
1000	250	302816	52049	250767	354865
1000	275	313020	51672	261348	364692
1000	300	323225	51363	271862	374588
1000	325	333430	51124	282306	384554
1000	350	343635	50956	292679	394591
1000	375	353839	50858	302981	404697
1000	400	364044	50833	313211	414877
1000	425	374249	50878	323371	425127
1000	450	384454	50996	333458	435450
1000	475	394658	51184	343474	445842
1000	500	404863	51442	353421	456305
1000	525	415068	51770	363298	466838
1000	550	425273	52165	373108	477438
1000	575	435477	52627	382850	488104
1000	600	445682	53153	392529	498835

Appendix B:

RI/FS COST INTERVALS

DEPTH	ANALYSIS	COST	INTERVAL	LOW	HIGH
1050	200	287896	53466	234430	341362
1050	225	298100	52934	245166	351034
1050	250	308305	52465	255840	360770
1050	275	318510	52063	266447	370573
1050	300	328715	51728	276987	380443
1050	325	338919	51462	287457	390381
1050	350	349124	51266	297858	400390
1050	375	359329	51140	308189	410469
1050	400	369534	51085	318449	420619
1050	425	379738	51101	328637	430839
1050	450	389943	51189	338754	441132
1050	475	400148	51348	348800	451496
1050	500	410353	51576	358777	461929
1050	525	420557	51874	368683	472431
1050	550	430762	52241	378521	483003
1050	575	440967	52674	388293	493641
1050	600	451172	53172	398000	504344
1050	625	461376	53733	407643	515109
1050	650	471581	54355	417226	525936
1050	675	481786	55037	426749	536823
1050	700	491991	55776	436215	547767
1100	200	293385	53956	239429	347341
1100	225	303590	53401	250189	356991
1100	250	313795	52909	260886	366704
1100	275	323999	52482	271517	376481
1100	300	334204	52121	282083	386325
1100	325	344409	51828	292581	396237
1100	350	354614	51604	303010	406218
1100	375	364818	51450	313368	416268
1100	400	375023	51367	323656	426390
1100	425	385228	51354	333874	436582
1100	450	395433	51413	344020	446846
1100	475	405637	51542	354095	457179
1100	500	415842	51741	364101	467583
1100	525	426047	52010	374037	478057
1100	550	436252	52346	383906	488598
1100	575	446456	52750	393706	499206
1100	600	456661	53220	403441	509881
1100	625	466866	53753	413113	520619
1100	650	477071	54348	422723	531419
1100	675	487275	55002	432273	542277
1100	700	497480	55715	441765	553195

Appendix B:

RI/FS COST INTERVALS

DEPTH	ANALYSIS	COST	INTERVAL	LOW	HIGH
1150	200	298875	54471	244404	353346
1150	225	309079	53894	255185	362973
1150	250	319284	53379	265905	372663
1150	275	329489	52927	276562	382416
1150	300	339694	52541	287153	392235
1150	325	349898	52222	297676	402120
1150	350	360103	51971	308132	412074
1150	375	370308	51790	318518	422098
1150	400	380513	51678	328835	432191
1150	425	390717	51637	339080	442354
1150	450	400922	51666	349256	452588
1150	475	411127	51766	359361	462893
1150	500	421332	51936	369396	473268
1150	525	431536	52175	379361	483711
1150	550	441741	52482	389259	494223
1150	575	451946	52857	399089	504803
1150	600	462151	53298	408853	515449
1150	625	472355	53802	418553	526157
1150	650	482560	54369	428191	536929
1150	675	492765	54997	437768	547762
1150	700	502970	55683	447287	558653

Appendix C:

RI COST INTERVALS

DEPTH	ANALYSIS	COST	INTERVAL	LOW	HIGH
0	25	36044	48818	0	84862
0	50	46249	48827	0	95076
0	75	56453	48911	7542	105364
0	100	66658	49069	17589	115727
0	125	76863	49300	27563	126163
0	150	87068	49604	37464	136672
50	25	41533	48745	0	90278
50	50	51738	48723	3015	100461
50	75	61943	48777	13166	110720
50	100	72148	48905	23243	121053
50	125	82352	49107	33245	131459
50	150	92557	49382	43175	141939
100	25	47023	48704	0	95727
100	50	57228	48652	8576	105880
100	75	67432	48675	18757	116107
100	100	77637	48773	28864	126410
100	125	87842	48945	38897	136787
100	150	98047	49191	48856	147238
150	25	52512	48696	3816	101208
150	50	62717	48614	14103	111331
150	75	72922	48606	24316	121528
150	100	83127	48673	34454	131800
150	125	93331	48815	44516	142146
150	150	103536	49032	54504	152568
200	25	58002	48721	9281	106723
200	50	68207	48608	19599	116815
200	75	78411	48570	29841	126981
200	100	88616	48607	40009	137223
200	125	98821	48718	50103	147539
200	150	109026	48904	60122	157930

Appendix C:

RI COST INTERVALS

DEPTH	ANALYSIS	COST	INTERVAL	LOW	HIGH
250	25	63491	48778	14713	112269
250	50	73696	48635	25061	122331
250	75	83901	48566	35335	132467
250	100	94106	48572	45534	142678
250	125	104310	48654	55656	152964
250	150	114515	48810	65705	163325
250	175	124720	49039	75681	173759
250	200	134925	49342	85583	184267
250	225	145129	49716	95413	194845
250	250	155334	50160	105174	205494
250	275	165539	50672	114867	216211
300	25	68981	48868	20113	117849
300	50	79186	48694	30492	127880
300	75	89390	48595	40795	137985
300	100	99595	48571	51024	148166
300	125	109800	48622	61178	158422
300	150	120005	48747	71258	168752
300	175	130209	48947	81262	179156
300	200	140414	49220	91194	189634
300	225	150619	49565	101054	200184
300	250	160824	49981	110843	210805
300	275	171028	50465	120563	221493
350	25	74470	48990	25480	123460
350	50	84675	48787	35888	133462
350	75	94880	48657	46223	143537
350	100	105085	48603	56482	153688
350	125	115289	48623	66666	163912
350	150	125494	48718	76776	174212
350	175	135699	48887	86812	184586
350	200	145904	49130	96774	195034
350	225	156108	49446	106662	205554
350	250	166313	49833	116480	216146
350	275	176518	50289	126229	226807
350	300	186723	50813	135910	237536

Appendix C:

RI COST INTERVALS

DEPTH	ANALYSIS	COST	INTERVAL	LOW	HIGH
400	25	79960	49145	30815	129105
400	50	90165	48912	41253	139077
400	75	100369	48752	51617	149121
400	100	110574	48667	61907	159241
400	125	120779	48656	72123	169435
400	150	130984	48721	82263	179705
400	175	141188	48860	92328	190048
400	200	151393	49073	102320	200466
400	225	161598	49359	112239	210957
400	250	171803	49716	122087	221519
400	275	182007	50144	131863	232151
400	300	192212	50640	141572	242852
450	25	85449	49331	36118	134780
450	50	95654	49069	46585	144723
450	75	105859	48879	56980	154738
450	100	116064	48764	67300	164828
450	125	126268	48723	77545	174991
450	150	136473	48757	87716	185230
450	175	146678	48865	97813	195543
450	200	156883	49048	107835	205931
450	225	167087	49304	117783	216391
450	250	177292	49632	127660	226924
450	275	187497	50030	137467	237527
450	300	197702	50498	147204	248200
500	25	90939	49549	41390	140488
500	50	101144	49258	51886	150402
500	75	111348	49038	62310	160386
500	100	121553	48893	72660	170446
500	125	131758	48822	82936	180580
500	150	141963	48825	93138	190788
500	175	152167	48903	103264	201070
500	200	162372	49055	113317	211427
500	225	172577	49281	123296	221858
500	250	182782	49579	133203	232361
500	275	192986	49949	143037	242935
500	300	203191	50388	152803	253579

Appendix C:

RI COST INTERVALS

DEPTH	ANALYSIS	COST	INTERVAL	LOW	HIGH
550	25	96428	49798	46630	146226
550	50	106633	49478	57155	156111
550	75	116838	49230	67608	166068
550	100	127043	49054	77989	176097
550	125	137247	48953	88294	186200
550	150	147452	48926	98526	196378
550	175	157657	48974	108683	206631
550	200	167862	49095	118767	216957
550	225	178066	49291	128775	227357
550	250	188271	49559	138712	237830
550	275	198476	49899	148577	248375
550	300	208681	50309	158372	258990
600	25	101918	50078	51840	151996
600	50	112123	49730	62393	161853
600	75	122327	49452	72875	171779
600	100	132532	[illegible]9248	83284	181780
600	125	142737	[illegible]9117	93620	191854
600	150	152942	4[illegible]059	103883	202001
600	175	163146	49076	114070	212222
600	200	173351	49168	124183	222519
600	225	183556	49333	134223	232889
600	250	193761	49571	144190	243332
600	275	203965	49881	154084	253846
600	300	214170	50261	163909	264431
650	25	107407	50388	57019	157795
650	50	117612	50012	67600	167624
650	75	127817	49706	78111	177523
650	100	138022	49473	88549	187495
650	125	148226	49312	98914	197538
650	150	158431	49225	109206	207656
650	175	168636	49212	119424	217848
650	200	178841	49272	129569	228113
650	225	189045	49407	139638	238452
650	250	199250	49615	149635	248865
650	275	209455	49894	159561	259349
650	300	219660	50245	169415	269905

Appendix C:

RI COST INTERVALS

DEPTH	ANALYSIS	COST	INTERVAL	LOW	HIGH
700	25	112897	50727	62170	163624
700	50	123102	50324	72778	173426
700	75	133306	49991	83315	183297
700	100	143511	49729	93782	193240
700	125	153716	49539	104177	203255
700	150	163921	49422	114499	213343
700	175	174125	49379	124746	223504
700	200	184330	49409	134921	233739
700	225	194535	49513	145022	244048
700	250	204740	49691	155049	254431
700	275	214944	49940	165004	264884
700	300	225149	50261	174888	275410
750	25	118386	51095	67291	169481
750	50	128591	50666	77925	179257
750	75	138796	50305	88491	189101
750	100	149001	50015	98986	199016
750	125	159205	49796	109409	209001
750	150	169410	49650	119760	219060
750	175	179615	49577	130038	229192
750	200	189820	49578	140242	239398
750	225	200024	49651	150373	249675
750	250	210229	49798	160431	260027
750	275	220434	50018	170416	270452
750	300	230639	50309	180330	280948
800	25	123876	51492	72384	175368
800	50	134081	51037	83044	185118
800	75	144285	50649	93636	194934
800	100	154490	50332	104158	204822
800	125	164695	50085	114610	214780
800	150	174900	49910	124990	224810
800	175	185104	49807	135297	234911
800	200	195309	49778	145531	245087
800	225	205514	49821	155693	255335
800	250	215719	49938	165781	265657
800	275	225923	50127	175796	276050
800	300	236128	50388	185740	286516

Appendix C:

RI COST INTERVALS

DEPTH	ANALYSIS	COST	INTERVAL	LOW	HIGH
850	100	159980	50678	109302	210658
850	125	170184	50403	119781	220587
850	150	180389	50199	130190	230588
850	175	190594	50068	140526	240662
850	200	200799	50009	150790	250808
850	225	211003	50023	160980	261026
850	250	221208	50109	171099	271317
850	275	231413	50268	181145	281681
850	300	241618	50499	191119	292117
900	100	165469	51053	114416	216522
900	125	175674	50751	124923	226425
900	150	185879	50519	135360	236398
900	175	196083	50359	145724	246442
900	200	206288	50271	156017	256559
900	225	216493	50255	166238	266748
900	250	226698	50311	176387	277009
900	275	236902	50440	186462	287342
900	300	247107	50641	196466	297748
950	100	170959	51456	119503	222415
950	125	181163	51127	130036	232290
950	150	191368	50868	140500	242236
950	175	201573	50680	150893	252253
950	200	211778	50563	161215	262341
950	225	221982	50517	171465	272499
950	250	232187	50544	181643	282731
950	275	242392	50643	191749	293035
950	300	252597	50814	201783	303411
1000	100	176448	51887	124561	228335
1000	125	186653	51532	135121	238185
1000	150	196858	51246	145612	248104
1000	175	207062	51030	156032	258092
1000	200	217267	50884	166383	268151
1000	225	227472	50810	176662	278282
1000	250	237677	50808	186869	288485
1000	275	247881	50877	197004	298758
1000	300	258086	51018	207068	309104

Appendix D: Model SAS Computer Programs

Model 1 Program

```
DATA ONE;
INFILE ALL1;
INPUT COST BORINGS WELLS SOIL WATER SED BDEPTH WDEPTH D;
ANALYSIS=SOIL+WATER+SED;
DEPTH=BDEPTH+WDEPTH;
PROC PRINT;
PROC CORR;
 VAR COST ANALYSIS BDEPTH WDEPTH;


PROC REG;
 MODEL COST=D ANALYSIS BDEPTH WDEPTH/ALL PARTIAL;
 OUTPUT OUT=ONE P=PREDICT R=RESID;

PROC PLOT;
 PLOT COST*ANALYSIS;
 PLOT RESID*ANALYSIS/VREF=0;

 PLOT COST*BDEPTH;
 PLOT RESID*BDEPTH/VREF=0;

 PLOT COST*WDEPTH;
 PLOT RESID*WDEPTH/VREF=0;
PROC UNIVARIATE DATA =ONE NORMAL PLOT;
 VAR RESID;

[FILE NAME: ALL1.SWP]
```

Model 2 Program

```
OPTIONS LINESIZE=70 PAGESIZE=55;

DATA ONE;
INFILE ALL1;
INPUT COST BORINGS WELLS SOIL WATER SED BDEPTH WDEPTH D;
ANALYSIS=SOIL+WATER+SED;
DEPTH=BDEPTH+WDEPTH;
PROC PRINT;
PROC CORR;
 VAR COST ANALYSIS DEPTH;
PROC REG;
 MODEL COST=D ANALYSIS DEPTH/ALL;
 OUTPUT OUT=ONE P=PREDICT R=RESID;

PROC PLOT;
 PLOT COST*ANALYSIS;
 PLOT RESID*ANALYSIS/VREF=0;

 PLOT COST*DEPTH;
 PLOT RESID*DEPTH/VREF=0;
PROC UNIVARIATE DATA =ONE NORMAL PLOT;
 VAR RESID;


[FILE NAME: ALL1A.SWP]
```

Model 3 Program

```
DATA ONE;
INFILE ALL1;
INPUT COST BORINGS WELLS SOIL WATER SED BDEPTH WDEPTH D;
ANALYSIS=SOIL+WATER+SED;
DEPTH=BDEPTH+WDEPTH;
SOLID=SOIL+SED;
HOLES=BORINGS+WELLS;
PROC REG;
 MODEL COST=D ANALYSIS WDEPTH/ALL;
 OUTPUT OUT=ONE P=PREDICT R=RESID;

PROC PLOT;
 PLOT COST*ANALYSIS;
 PLOT RESID*ANALYSIS/VREF=0;

 PLOT COST*WDEPTH;
 PLOT RESID*WDEPTH/VREF=0;
PROC UNIVARIATE DATA =ONE NORMAL PLOT;
 VAR RESID;


[FILE NAME: ALL2.SWP]
```

Model 4 Program

```
OPTIONS LINESIZE=78 PAGESIZE=60;
DATA ONE;
INFILE ALL1;
INPUT COST BORINGS WELLS SOIL WATER SED BDEPTH WDEPTH D;
ANALYSIS=SOIL+WATER+SED;
DEPTH=BDEPTH+WDEPTH;
SQRTAN=SQRT(ANALYSIS);
SQRTD=SQRT(DEPTH);

PROC PRINT;
PROC REG;
 MODEL COST=D SQRTAN SQRTD/ALL PARTIAL;
 OUTPUT OUT=ONE P=PREDICT R=RESID;
 U95=COST;
 L95=COST;

PROC PLOT;
 PLOT COST*SQRTAN;
 PLOT RESID*SQRTAN/VREF=0;

 PLOT COST*SQRTD;
 PLOT RESID*SQRTD/VREF=0;

PROC UNIVARIATE DATA =ONE NORMAL PLOT;
 VAR RESID;

[File name: ALL5.SWP]
```

Appendix E: Model 3 SAS Output

OBS	COST	BORINGS	WELLS	SOIL	WATER	SED	BDEPTH	WDEPTH	D	ANALYSIS	DEPTH
1	485664	22	7	441	240	71	880	280	1	752	1160
2	355263	23	21	255	259	38	575	420	1	552	995
3	79418	6	4	78	34	0	180	160	0	112	340
4	203828	18	0	247	34	34	180	0	1	315	180
5	229745	24	4	216	32	0	140	160	1	248	300
6	19389	20	3	18	10	0	100	60	0	28	160
7	57553	22	9	64	40	0	88	180	0	104	268
8	39487	5	2	75	32	0	25	40	0	107	65
9	22962	8	2	15	34	12	40	40	0	61	80
10	21430	10	2	21	20	0	40	40	0	41	80
11	145104	4	0	15	51	0	4	0	0	66	4
12	194565	3	0	12	75	0	3	0	0	87	3
13	378247	8	6	162	79	16	120	270	1	257	390
14	278674	0	3	40	148	0	0	1550	0	188	1550
15	115024	0	0	80	0	0	0	0	0	80	0
16	148065	7	0	132	0	0	90	0	1	132	90
17	72104	0	0	36	0	28	0	0	1	64	0
18	115743	4	0	130	0	0	0	0	1	130	0
19	142910	3	3	78	54	12	45	165	1	144	210
20	229031	5	4	108	103	20	65	250	1	231	315
21	275936	8	5	159	106	0	120	125	1	265	245
22	386318	5	12	166	154	0	100	800	1	320	900
23	170501	8	3	64	76	0	200	115	1	140	315
24	276233	8	3	128	107	0	200	75	1	235	275
25	157260	0	0	0	167	0	0	0	0	167	0
26	18143	2	0	15	0	0	40	0	0	15	40
27	55846	6	0	63	0	0	60	0	0	63	60
28	113283	0	3	0	43	0	0	450	0	43	450
29	108281	0	3	0	33	0	0	600	0	33	600
30	44473	1	0	54	0	0	30	0	0	54	30
31	208544	8	0	253	0	0	240	0	0	253	240
32	40376	6	0	41	0	0	30	0	0	41	30
33	83636	3	0	95	0	0	90	0	0	95	90
34	158670	0	3	0	40	0	0	950	0	40	950
35	5635	1	0	4	0	0	20	0	0	4	20
36	74467	6	0	80	0	0	90	0	0	80	90
37	158688	0	2	0	68	0	0	730	0	68	730
38	157133	5	1	138	32	0	300	365	0	170	665
39	19914	2	0	55	0	0	120	0	0	55	120
40	20186	1	0	31	0	0	60	0	0	31	60
41	23545	1	0	33	12	0	15	0	0	45	15
42	23545	1	0	33	12	0	15	0	0	45	15
43	82971	4	0	146	0	0	240	0	0	146	240
44	82971	4	0	146	0	0	240	0	0	146	240
45	218403	4	1	198	42	0	360	365	0	240	725
46	39774	3	0	50	0	0	180	0	0	50	180
47	37448	2	0	58	0	0	100	0	0	58	100
48	331478	10	10	256	153	55	400	300	1	464	700
49	85323	0	0	0	32	40	0	0	1	72	0

Correlation Analysis

'VAR' Variables: COST ANALYSIS DEPTH

Simple Statistics

Variable	N	Mean	Std Dev	Sum	Minimum	Maximum
COST	49	138636	115034	6793187	5635.0	485664
ANALYSIS	49	145.7	144.4	7137.0	4.0000	752.0
DEPTH	49	292.1	352.7	14315.0	0	1550.0

Pearson Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 49

	COST	ANALYSIS	DEPTH
COST	1.00000	0.87316	0.68508
	0.0	0.0001	0.0001
ANALYSIS	0.87316	1.00000	0.58867
	0.0001	0.0	0.0001
DEPTH	0.68508	0.58867	1.00000
	0.0001	0.0001	0.0

Variable	Variance Inflation
Intercept	0.000000
D	1.71870
Analysis	2.54099
Depth	1.66387

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	3	539307982643	17976932754R	84.386	0.0001
Error	45	95864666715	2130325927		
C Total	48	635172649358			

Root MSE	46155.45392	R-square	0.8491
Dep Mean	138636.46939	Adj R-sq	0.8390
C.V.	33.29243		

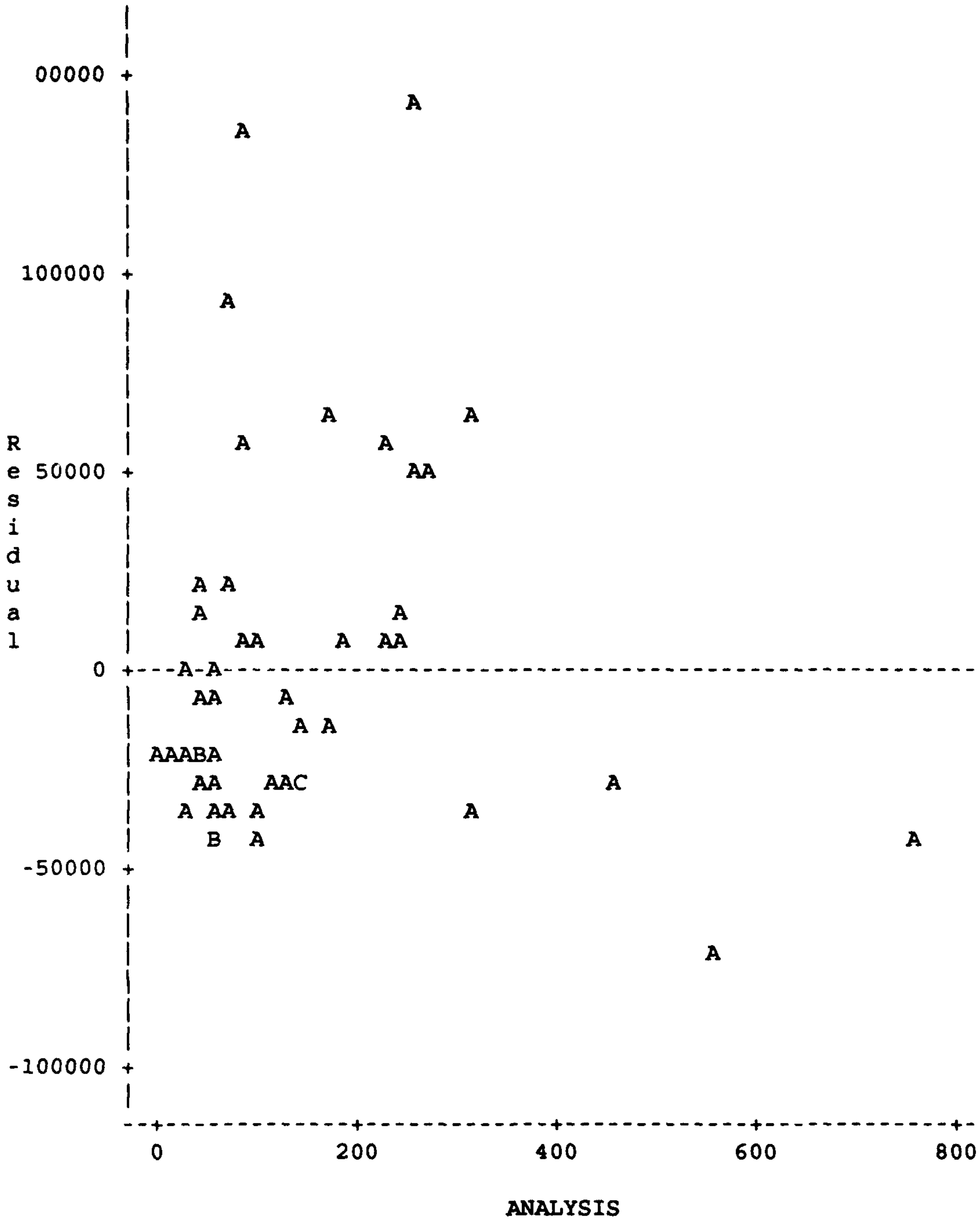
Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	25839	9691.8757115	2.666	0.0106
D	1	65139	18433.391186	3.534	0.0010
ANALYSIS	1	408.186041	73.67051652	5.541	0.0001
DEPTH	1	109.788879	24.36676013	4.506	0.0001

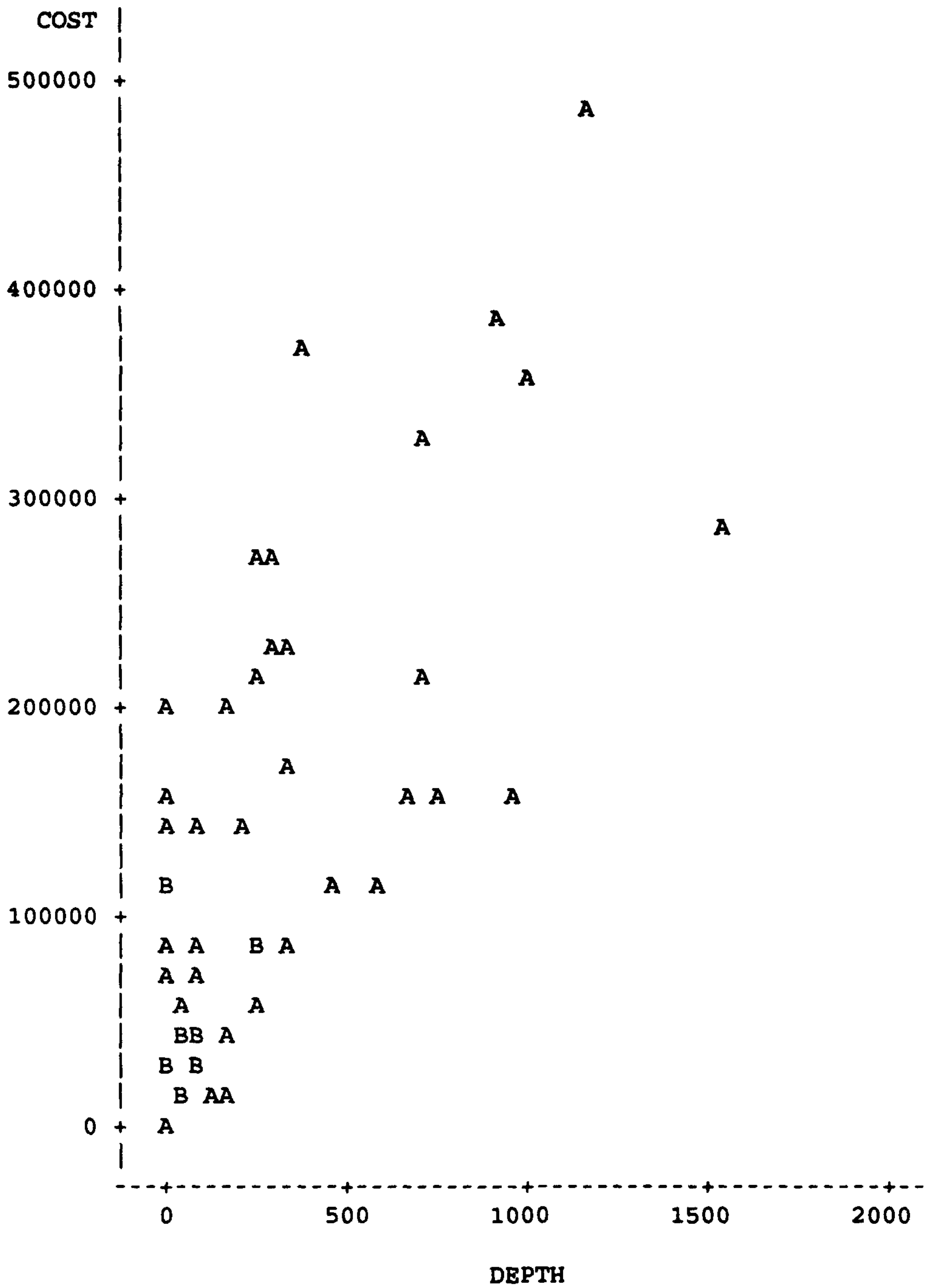
Obs	Upper95% Predict	Residual	Std Err Residual	Student Residual	-2-1-0 1 2	Cook's D
1	636580	-39625.1	34748.63	-1.140	| **| |	0.248
2	526958	-70273.7	41532.59	-1.692	| ***| |	0.168
3	203316	-29466.0	45413.65	-0.649	| *| |	0.003
4	336288	-35490.7	44075.88	-0.805	| *| |	0.016
5	321021	4600.1	44661.62	0.103	| | |	0.000
6	149435	-35445.4	45326.99	-0.782	| *| |	0.006
7	192102	-40160.7	45436.07	-0.884	| *| |	0.006
8	171689	-37164.1	45101.12	-0.824	| *| |	0.008
9	154121	-36559.4	45327.68	-0.807	| *| |	0.006
10	145956	-29927.7	45328.33	-0.660	| *| |	0.004
11	148164	91885.6	45148.80	2.035	| |**** |	0.047
12	156834	132884	45041.21	2.950	| |***** |	0.109
13	334550	139547	44675.42	3.124	| |******|	0.164
14	382339	5923.3	36057.78	0.164	| | |	0.004
15	153587	56530.2	45072.66	1.254	| |** |	0.019
16	251924	-6674.7	43959.39	-0.152	| | |	0.001
17	215903	-44998.0	43061.67	-1.045	| **| |	0.041
18	241426	-28299.3	43850.02	-0.645	| *| |	0.011
19	269814	-29902.6	44058.85	-0.679	| *| |	0.011
20	315785	9178.4	44631.91	0.206	| | |	0.001
21	322067	49890.3	44584.52	1.119	| |** |	0.022
22	418671	65910.4	43363.78	1.520	| |*** |	0.077
23	280119	-12206.6	43835.01	-0.278	| | |	0.002
24	313024	59139.2	44633.24	1.325	| |** |	0.030
25	190877	63254.0	44129.57	1.433	| |** |	0.048
26	131149	-18210.3	45226.76	-0.403	| | |	0.002
27	152817	-2296.0	45288.80	-0.051	| | |	0.000
28	188274	20487.0	44871.53	0.457	| | |	0.003
29	202261	3098.6	44016.70	0.070	| | |	0.000
30	145937	-6701.7	45244.02	-0.148	| | |	0.000
31	253120	53084.6	43698.31	1.215	| |** |	0.043
32	140609	-5492.3	45254.88	-0.121	| | |	0.000
33	169266	9138.4	45240.52	0.202	| | |	0.000
34	248521	12204.2	41148.06	0.297	| | |	0.006
35	124582	-24032.5	45165.18	-0.532	| *| |	0.003
36	163023	6092.2	45302.97	0.134	| | |	0.000
37	231418	24946.5	43689.16	0.571	| |* |	0.009
38	263955	-11107.2	44746.93	-0.248	| | |	0.001
39	155958	-41549.9	45381.68	-0.916	| *| |	0.007
40	139753	-24894.1	45290.13	-0.550	| *| |	0.003
41	140655	-22309.2	45223.77	-0.493	| | |	0.003
42	140655	-22309.2	45223.77	-0.493	| | |	0.003
43	206601	-28812.5	45215.46	-0.637	| *| |	0.004
44	206601	-28812.5	45215.46	-0.637	| *| |	0.004
45	299912	15002.5	44322.93	0.338	| | |	0.002
46	160461	-26236.3	45404.42	-0.578	| *| |	0.003
47	155031	-23044.6	45359.31	-0.508	| *| |	0.002
48	455714	-25750.6	43239.22	-0.596	| *| |	0.012
49	218946	-35044.5	43187.16	-0.811	| *| |	0.023

```
      Plot of COST*ANALYSIS.  Legend: A = 1 obs, B = 2 obs, etc.

   COST |
        |
 500000 +
        |                                               A
        |
        |
        |
        |
        |
 400000 +
        |                     A
        |                 A
        |                                   A
        |
        |                              A
        |
 300000 +
        |             A
        |                A A
        |
        |
        |                AA
        |                AA
 200000 +       A             A
        |
        |          A
        |    A A     B
        |      A   AA
        |
        |    AA A  A
 100000 +
        |      A AA B
        |      AA
        |      A A
        |    AC  A
        |    ABA
        |   ABA
      0 +  A
        |
        ---+-----------+-----------+-----------+-----------+--
           0          200         400         600         800

                               ANALYSIS
```

Plot of RESID*ANALYSIS. Legend: A = 1 obs, B = 2 obs, etc.



Plot of COST*DEPTH. Legend: A = 1 obs, B = 2 obs, etc.



```
      Plot of RESID*DEPTH.  Legend: A = 1 obs, B = 2 obs, etc.
        |
        |
 150000 +
        |            A
        | A
        |
        |
        |
        |
 100000 +
        | A
        |
        |
        |
        | A                        A
R       | A       A
e 50000 +        B
s       |
i       |
d       |
u       |              A      A
a       |                     A      A
l       |    B    AA                                 A
      0 +---A--------------A----------------------------------------
        |  B A
        |          A         A
        | BBAA
        | A A  AAB  A         A
        | A B AA
        | A  A    A             A
 -50000 +
        |
        |
        |                   A
        |
        |
        |
-100000 +
        |
        --+-------------+-------------+-------------+-------------+-
          0            500           1000          1500          2000

                                    DEPTH
```

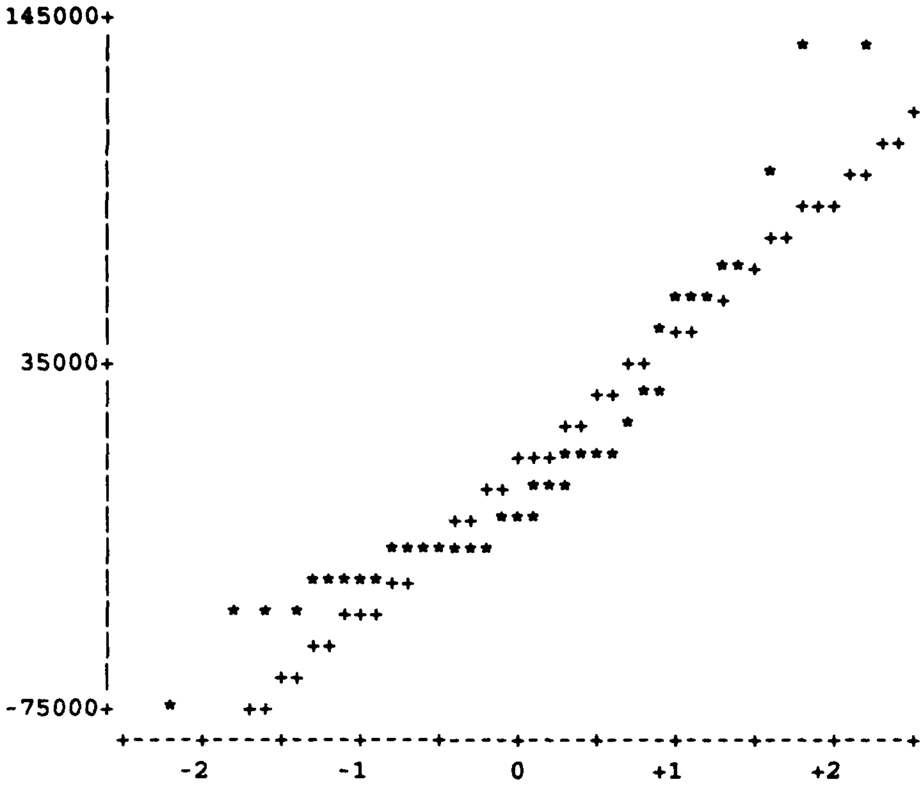
Univariate Procedure

```
Variable=RESID          Residual

               Stem Leaf                     #             Boxplot
                 14 0                        1                *
                 13 3                        1                0
                 12
                 11
                 10
                  9 2                        1                0
                  8
                  7
                  6 36                       2                |
                  5 0379                     4                |
                  4                                           |
                  3                                           |
                  2 05                       2                |
                  1 25                       2             +-----+
                  0 356699                   6             |  +  |
                 -0 7752                     4             |     |
                 -1 821                      3             *-----*
                 -2 99986654322             11             +-----+
                 -3 7755500                  7                |
                 -4 5200                     4                |
                 -5                                           |
                 -6                                           |
                 -7 0                        1                |
                    ----+----+----+----+
                Multiply Stem.Leaf by 10**+4
```

Univariate Procedure

Variable=RESID Residual

Normal Probability Plot



<u>Bibliography</u>

1. Bingham, Beverly B. and others. <u>The Base Level Cost Analysis Handbook</u>. Prepared for the Deputy Comptroller, Cost and Economics, SAF/AQSS, The Pentagon, Washington DC: The Analytical Sciences Corporation, 8 August 1988.

2. Brown, Andrew C. "The Devil's Brew in the Love Canal." <u>Fortune</u>: 76, 19 November 1979.

3. Defense Systems Management College, <u>Risk Management (Concept and Guidance)</u>, Fort Belvoir VA: DSMC, March 1989.

4. Department of the Air Force. <u>AFSC Cost Estimating Handbook</u>, Volume 1. Reading, MA: The Analytic Sciences Corporation (TASC), (no date).

5. Department of the Air Force. <u>Air Combat Command Installation Restoration Program Remedial Project Manager's Guide</u>. ACC/CEVR, Langley AFB VA. November 1992.

6. Department of the Air Force. <u>Environmental Restoration Program Management Action Plan (MAP) Guidebook</u>. May 1992.

7. Department of the Air Force. <u>FY 1993-97 Defense Environmental Restoration Program Management Guidance for Non-Closure Bases</u>. Bolling AFB DC: HQ AF/CEVR, 1 March 1993.

8. Department of the Air Force. Memorandum: Remedial Action Cost Engineering and Requirements (RACER) System. Office of the Deputy Assistant Secretary of the Air Force (Environment, Safety and Occupational Health), Washington DC 20330-1000, 1 September 1992.

9. Department of the Air Force. RACER Remedial Action Cost Engineering and Requirements System ENVEST Environmental Cost Engineering Model Report. Tyndall AFB FL. 24 August 92.

10. Department of the Air Force. RACER Remedial Action Cost Engineering and Requirements System ENVEST Environmental Cost Engineering User's Manual. Tyndall AFB FL, 24 August 92.

11. Department of the Air Force. U.S. Air Force Installation Restoration Program Remedial Project Manager's Handbook. January 1992.

12. Department of Energy. Environmental Restoration and Waste Management Cost Assessment Team (EM-CAT) Handbook, Rev. 0, September 1990.

13. Diekmann, James. Cost and Schedule Risk Analysis Guidance Document. Report prepared for the U.S. Army Corps of Engineers. Lafayette CO. (No Date).

14. Dienemann, Paul F. Estimating Cost Uncertainty Using Monte Carlo Techniques. Contract AF49(638)-1700. The Rand Corp. Santa Monica CA. January 1966.

15. Environmental Protection Agency. Guidance for Conducting Remedial Investigation and Feasibility Studies Under CERCLA, Interim Final. OSWER Directive 9355.3-01. Washington: Office of Emergency and Remedial Response, U.S. EPA, October 1988.

16. Gallagher, W. E. and P.J. Palmisano. The User's Manual for the Independent Cost Estimating Contingency Analysis (ICECAN) Model. International Technology (IT) Corporation. Provided to the United States Department of Energy, Independent Cost Estimating. Washington DC (No Date).

17. Gregory, Rita A., Ph.D. Director of Construction Cost Management, Headquarters, Air Force Civil Engineering and Support Agency (HQ AFCESA/DC), Tyndall AFB FL. Telephone Interview. 22 November 1992.

18. Gregory, Rita A., Ph.D. Director of Construction Cost Management, Headquarters, Air Force Civil Engineering and Support Agency (AFCESA), Tyndall AFB FL. Telephone Interview. 17 August 1993,

19. "Guide to Major Air Force Installations Worldwide," Air Force Magazine, 75: 133-142 (May 1991).

20. Headquarters Air Combat Command. Environmental Pricing Guide for FY94 Program, Draft copy. Langley AFB VA, May 1993.

21. Hurley, Thomas, Director for Design Policy, Assistant Commander for Engineering and Design, Naval Facilities and Engineering Command (NAVFACENGCOM). Telephone Interview. 2 December 1992 and 16 August 1993.

22. Klee, Albert J. "AutoMOUSE An Improvement to the MOUSE Computerized Uncertainty Analysis System Operational Manual," EPA Project Summary. United States Environmental Protection Agency, Risk reduction Laboratory, Cincinnati OH, September 1992.

23. Klee, Albert J. "MOUSE - A computerized Uncertainty Analysis System." Hazardous Waste & Hazardous Materials. Mary Ann Liebert, Inc., Volume 7, Number 4: 373-384, 1990.

24. Lester, Ron. Chief, Environmental Restoration Branch, 6594 Air Base Group (6594 ABG/DEV), Wright-Patterson AFB OH. Personal interview. 14 April 1993.

25. Moore, Robert M., Chief Environmental Restoration Division, Headquarters Air Combat Command (HQ ACC/CEVR), Langley AFB VA. Telephone Interview. 3 June 1993.

26. Morse, Michael A., "Environmental Assessment and Remediation: Estimating the Costs of Uncertainty," Remediation, Volume 3, Number 2: 141-155, Spring 1993.

27. Naval Facilities Engineering Command. Hazardous, Toxic, and Radioactive Waste Historical Cost Analysis System, Version 1.0 [User's Manual]. Prepared for the Interagency Cost Estimating Group Hazardous for Hazardous and Toxic Waste Remediation. 4 December 1992.

28. Nelson, Major Stewart A. Defense Environmental Restoration Program Manager, Environmental Restoration Division, Directorate of Environmental Quality, HQ USAF (HQ USAF/CEVR), Bolling AFB DC. Personal Interview. 29 December 1992.

29. Netter, John and others. Applied Linear Regression Models (Second Edition). Boston: Richard D. Irwin, Inc., 1989.

30. Newbold, Paul. Statistics for Business and Economics (Third Edition). Englewood Cliffs NJ: Prentice-Hall, Inc., 1991.

31. Peterson, James D. Civil Engineer. U.S. Army Corps of Engineers - Missouri River Division (CEMRD-ED-CV), Omaha NE. Telephone Interview. 2 December 1992.

32. Queenan III, Charles J. "Identifying Uncertainty In Cleanup Cost Estimates. Should You Draw Another Card" Briefing Slides presented by Putnam, Hayes, & Barlett, Inc. Washington DC, 27 August 1991.

33. Ratliff, Wayne T., Program Manager, Environmental Restoration Division, Headquarters Air Material Command, Wright-Patterson AFB OH. Telephone Interview. 16 April 1992.

34. Roark, Carol L. Environmental Specialist, School of Civil Engineering and Services, Air Force Institute of Technology, Wright-Patterson AFB OH. Personal Interview. 26 August 1993.

35. Roark, Carol L. User's Guide to the WIMS DERA Software. Environmental Management, Headquarters Air Logistics Command (HQ AFLC/CEV) Wright-Patterson AFB OH, November 1991.

36. Scholtzhaur, Sandra D. and Ramon C. Littel. SAS System for Elementary Statistical Analysis. Cary NC: SAS Institute, Inc., 1987.

37. Schroeder, B.R. and J.B. Hartrung. The HAZRISK® Cleanup Report (Draft report). Prepared for the Department of Energy by Independent Project Analysis, Incorporated, Reston VA, 22090, February 1991.

38. Singleton, Roy A. Chief, Air Force Section, Hazardous & Toxic Waste Branch. U.S. Army Corps of Engineers - Omaha District, Omaha NE. Personal Interview. 9 July 1993.

39. United States Army Corps of Engineers. Management Action Plan, Ellsworth Air Force Base, Rapid City SD. Contract DACW45-91-D-0018 with Radian Corporation. Omaha NE, January 1993.

40. Unites States Code Congressional and Administrative News. "Comprehensive Environmental Response, Compensation, and Liability Act." Public Law No. 210, 96th Congress, 2nd Session. St Paul MN: West Publishing 1981.

41. Whalen, Thomas A. Estimator, Environmental Restoration Programs. Headquarters, Environmental Protection Agency. Crystal City VA. Personal Interview, 15 June 93.

42. Wilson, Robert D., IV. Class handout, ENV 417, IRP Overview Briefing. School of Civil Engineering and Services, Air Force Institute of Technology (AFIT/CEV), Wright-Patterson AFB OH, (July 1993).

43. Wilson, Captain Robert D., IV. Instructor, Environmental Management, School of Civil Engineering, Air Force Institute of Technology (AFIT/CEV), Wright-Patterson AFB OH. Personal Interview. 25 August 1993.

44. Zugay, Anthony. Technical Associate, GM-15, Base Closure Restoration Division, Air Force Center for Environmental Excellence (AFCEE/ESB), Brooks AFB TX. Telephone Interview. 21 August 1992.

Vita

Captain Kurt Held was born on 19 August 1961 in Idaho Falls, Idaho. He graduated from Granda High School in Livermore, California in 1979 and enlisted in the Air Force. Upon completing basic and technical training he was stationed at Spangdahlem AB, Germany as a Security Policeman. He was accepted to the Air Force Academy and graduated with the Class of 1985. Captain Held was then assigned to Laughlin AFB. He was reassigned as a Financial Analyst for the Launch Vehicle Program Office at Los Angeles AFS, California. In 1988, Captain Held lead the Chemical Systems Branch, which conducted environmental research in support of Air Force's launch vehicle programs. In 1991, Captain Held was assigned to the Satellite Control and Data Handled Program Office. There he developed computerized financial management for the Satellite Control Network. Captain Held entered the School of Logistics and Acquisition Management, Air Force Institute of Technology, in May 1992.

Permanent Address: 534 Yosemite Dr.
Livermore, California 94550

Vita

Captain Perry J. Shepler was born on 21 October 1958 in Rochester, New York. He graduated from H.W. Schroeder High School in Webster, New York in 1976 and attended Alfred University in Alfred, New York, graduating with a Bachelor of Science in Accounting in May 1981. Upon graduation, he attended Officer Training School and received a reserve commission as a Second Lieutenant and entered Undergraduate Navigator Training at Mather AFB, California. In 1983, his first operational tour of duty began at Tinker AFB, Oklahoma, were he served as an E-3 navigator with the 964th AWAC Squadron, as an instructor navigator with the 966th AWACT Squadron, and as an standardization and evaluation navigator with 552 AWAC Wing. In 1989, he was reassigned to the 10th ACC Squadron at RAF Mildenhall, United Kingdom, as an EC-135 navigator and then as a standardization and evaluation navigator with 513 ACC Wing. When the 513 ACCW deactivated in 1992, he was reassigned to the 100th Wing as a Tanker Task Force Planner until entering the School of Logistics and Acquisition Management, Air Force Institute of Technology, in May 1992.

Permanent Address: 227 Curtice Park
Webster, New York 14580

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1993	Master's Thesis

4. TITLE AND SUBTITLE

QUANTIFICATION OF UNCERTAINTY IN THE REMEDIAL INVESTIGATION/FEASIBILITY STUDIES PROCESS

5. FUNDING NUMBERS

6. AUTHOR(S)

Kurt C. Held, Captain, USAF
Perry J. Shepler, Captain, USAF

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Air Force Institute of Technology, WPAFB OH 45433-6583

8. PERFORMING ORGANIZATION REPORT NUMBER

AFIT/GCA/LAS/93S-6

9. SPONSORING MONITORING AGENCY NAME(S) AND ADDRESS(ES)

HQ AFCESA/DC, Tyndall AFB FL 32403-6001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

Approved for public release; distribution unlimited

12a. DISTRIBUTION AVAILABILITY STATEMENT

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This thesis developed a method to bound cost estimates with a prediction interval of costs for the Remedial Investigation/Feasibility Study (RI/FS) phase of the Installation Remediation Program (IRP) process. The prediction interval provides a reasonableness cross check for RI/FS project cost estimates.

To develop the cost bounds, three major activities occurred. First, a database was developed from RI/FS projects managed by the Army Corps of Engineers. Second, a regression cost model was developed from the observations in the database. Third, a prediction interval specified at the 70 percent confidence level was derived from the cost model. This prediction interval provides a method to cross check RI/FS cost estimates. The prediction interval also provides a heuristic to bound RI/FS point estimates to incorporate uncertainty.

There are limitations to the cost model which affect the use of the cost intervals. The observations used to develop the cost model were limited to RI/FS projects whose field activities only included soil boring and monitoring well activities. The cost intervals should only be applied to similar type projects.

14. SUBJECT TERMS

Cost Uncertainty, RI/FS, ENVEST, Installation Restoration Program (IRP), environmental cost estimating

15. NUMBER OF PAGES 138

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

AFIT Control Number AFIT/GCA/LAS/93S-6

AFIT RESEARCH ASSESSMENT

The purpose of this questionnaire is to determine the potential for current and future applications of AFIT thesis research. Please return completed questionnaires to: DEPARTMENT OF THE AIR FORCE, AIR FORCE INSTITUTE OF TECHNOLOGY/LAC, 2950 P STREET, WRIGHT PATTERSON AFB OH 45433-7765

1. Did this research contribute to a current research project?

   a. Yes b. No

2. Do you believe this research topic is significant enough that it would have been researched (or contracted) by your organization or another agency if AFIT had not researched it?

   a. Yes b. No

3. The benefits of AFIT research can often be expressed by the equivalent value that your agency received by virtue of AFIT performing the research. Please estimate what this research would have cost in terms of manpower and/or dollars if it had been accomplished under contract or if it had been done in-house.

   Man Years ____________ $ ____________

4. Often it is not possible to attach equivalent dollar values to research, although the results of the research may, in fact, be important. Whether or not you were able to establish an equivalent value for this research (3, above) what is your estimate of its significance?

   a. Highly Significant b. Significant c. Slightly Significant d. Of No Significance

5. Comments

____________________ ____________________

Name and Grade Organization

____________________ ____________________

Position or Title Address